Induction Heating to Enable Mass Produced Composites

William Dykstra / PI

Luke Martin / Engineering Manager

VISION:

To change the way materials are processed using magnetic fields

MISSION:

Bring advanced processing and materials to industry through novel TECHNOLOGY, TOOLING, EQUIPMENT, and SERVICES for next generation manufacturing.

TEMPER MANAGEMENT TEAM:

Dr. Bonnie Dykstra, Ph. D., LPC, CAADC - CEO / President

Bonnie is responsible for the management of day-to-day operations & long-term decisions

William Dykstra, PI

Bill is responsible for Project Management, Marketing and Sales

Luke Martin, Engineering Manager

Luke is responsible for the mechanical design work.

CORE COMPETENCIES AND AREAS OF SPECIALIZATION:

All things **Smart Susceptor** and their applications in material processing. These areas of specialization include:

- Induction Heating
- Heat Blankets
- Equipment Integration
- Thermoplastic Composite Processing
- High Volume Matched Metal Tooling
- Tooling Tryout and Process Development
- Composite Repair
- Low Volume Prototyping
- Onsite Installation and Training

PRODUCTS WITH SIGNIFICANT COMMERCIAL SALES:

- Smart Susceptor Debulk System: **$2,400,000** (Boeing, West Jordan)
- Composite Process Development: **$650,000** (Joby Aviation)
- Thermoplastic Welding and Blade Development: **$2,200,000** (Boeing, Seattle)
- Thermoplastic processing development **$2,800,000** (Boeing, Seattle)
- Smart Susceptor Co-Bonding System: **$420,000** (Northrop)
- Horizontal Stabilizer Development: **$3,200,000** (Boeing, Seattle)
- Super Plastic Forming of Titanium **$650,000** (Boeing)
- Wing Skin and Co-bonding development **$3,350,000**

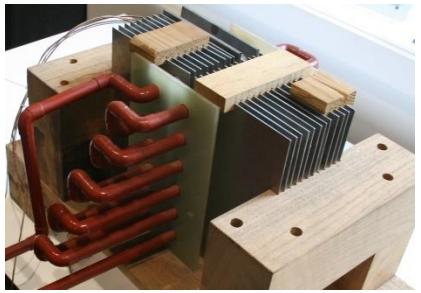
CONCISE HISTORY OF PREVIOUS FEDERAL AND NON-FEDERAL FUNDING/INVESTMENT:

- SBIR Phase II – Forming of High Hard Armor Using Mag-Forming (US Army)
- SBIR Phase II – Titanium Densification of Ti-64 powder into Near-Net Shapes (DOE)

TECHNOLOGY DEVELOPMENT AND PATENTS

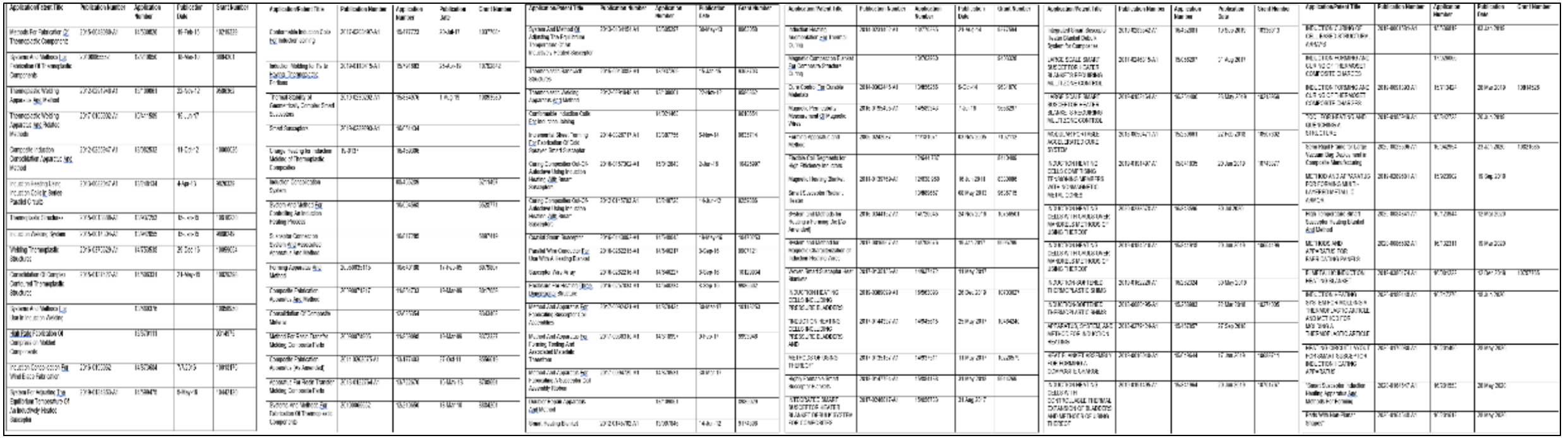
Temper Inc

Temper and The Boeing Company have been developing magnetic processing technologies together for over 15 years.



2006 First proof of concept heating fixture (smart susceptor)
2007 First proof of concept thermoplastic smart susceptor molding fixture
2010 First production capable thermoplastic smart susceptor mold
2011 Demonstrated first smart susceptor blanket
2012 Demonstrated Multi-blanket thermoset curing using smart susceptor blankets
2015 Demonstrated TiPAD titanium densification using recycled titanium 6Al4 powders using smart susceptors
2016 Designed, Built and installed first production 16 zone duel placement debulking system for 787 rear elevators at Boeings West Jordon Facility
2018 Demonstrated large scale 5 ft x 15 ft part / ceramic based smart susceptor molding

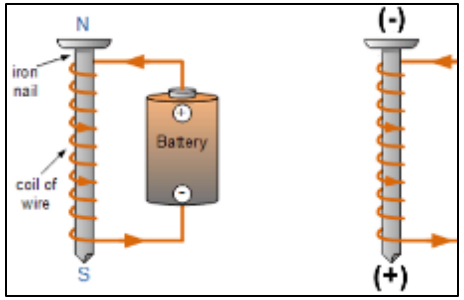
In total, The Boeing Company has **86** patents and Temper Inc. owns **18** in this processing area. In addition, Temper has obtained a license to make and produce equipment and / or products for the Boeing owned patents listed below. **TEMPER HAS LICENSE TO ALL OF THEM**



INDUCTION HEATING DEFINITION:

Induction heating is the process of heating an electrically conducting object by electromagnetic induction, through heat generated in the object by eddy currents.

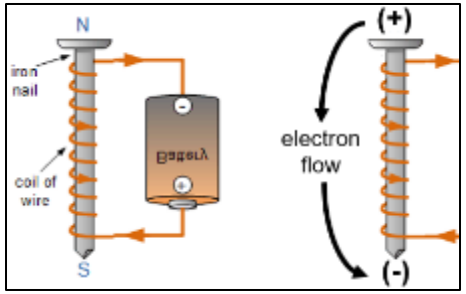
A SIMPLIFIED EXPLAINATION:



Recall this science experiment from grade-school…

Winding a coil of wire around a magnetic core, and apply a DC current, creates an electromagnet.

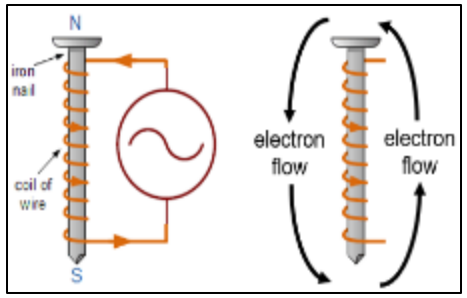
The magnetic field, created by the current in the coil, forces the free electrons in the magnetic core (nail) to one end of the core creating a negative charge. The other end of the core becomes positively charged.



If the polarity of the battery were reversed, the polarity of the magnetic field is also reversed.

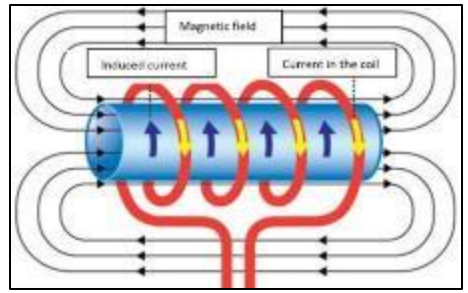
This would cause the free electrons that were in the head of the nail would flow to the tip of the nail.

Reversing the polarity “induced” a flow of electrons from one end of the magnetic core to the other.

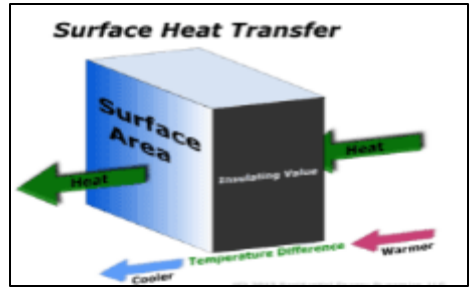


Replacing the DC power supply with an AC supply continuously reverses polarity of the magnetic field which induces a continuous current in the magnetic core.

This continuously induced current (created by the interaction of the magnetic field in the coil and the magnetic core) is the basis of induction heating.



A susceptor heats in the same way. The nail or tube from the previous examples are heated and the heat is conductively transferred to the part being processed.



… BUT HOW IS TEMPERATURE CONTROLLED?

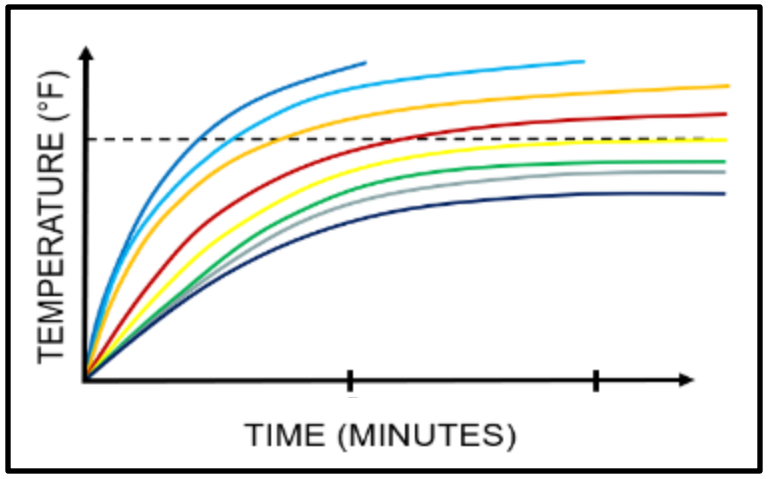
SMART SUSCEPTORS:

Background info.

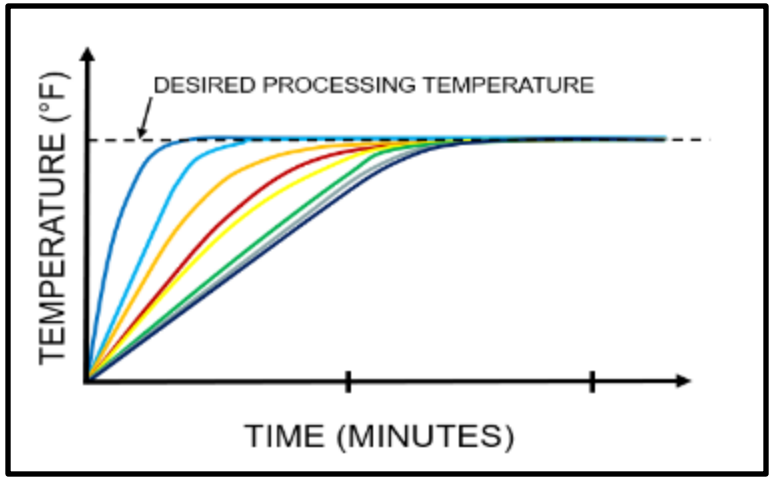
- A susceptor is a material or component is used between a magnetic field and a part to be produced by coupling into the magnetic field and either conductively transfers that heat to another part of the tooling or directly to a part
- The curie temperature is a temperature wherein all ferromagnetic materials become non-magnetic, which in an intrinsic property of the alloying content. **Knowledge and understanding of how the chemistry effects curie, is the fact separates us from our competitors.**
- The reference depth of an induction heating field acting on a susceptor that changes with heat.
- And some secret sauce.

A *Smart Susceptor* is a susceptor that **combines all three of the elements** noted above. In addition.

- The susceptor is designed in several different configurations. (looped, non-looped, as wires used in heating blankets and for welding thermoplastics)
- The Curie temperature is effected by alloying content, magnetic field strength and frequency.
- The reference depth changes with material and magnetic frequency.



Traditional Heating, approximation is made, heat induced and allowed to settle to an acceptable temperature range



Smart Susceptors can only heat to the pre-selected desired temperature

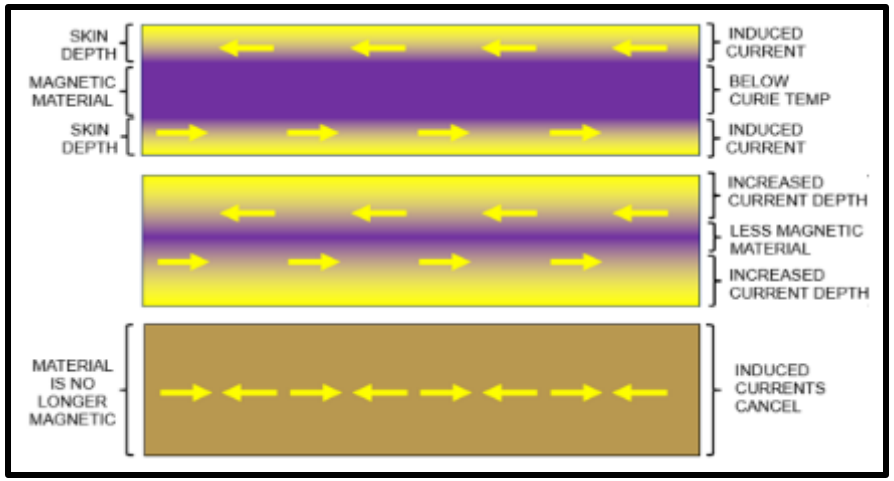


Chart showing how the reference depth changes as the smart susceptor becomes non-magnetic

SMART SUSCEPTOR – How it solves the problem statement

⇩ = BTU input

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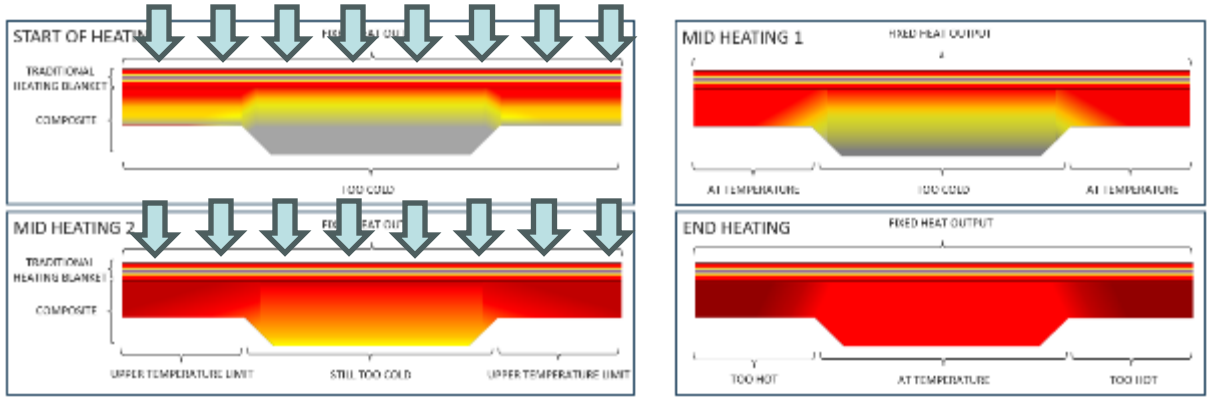
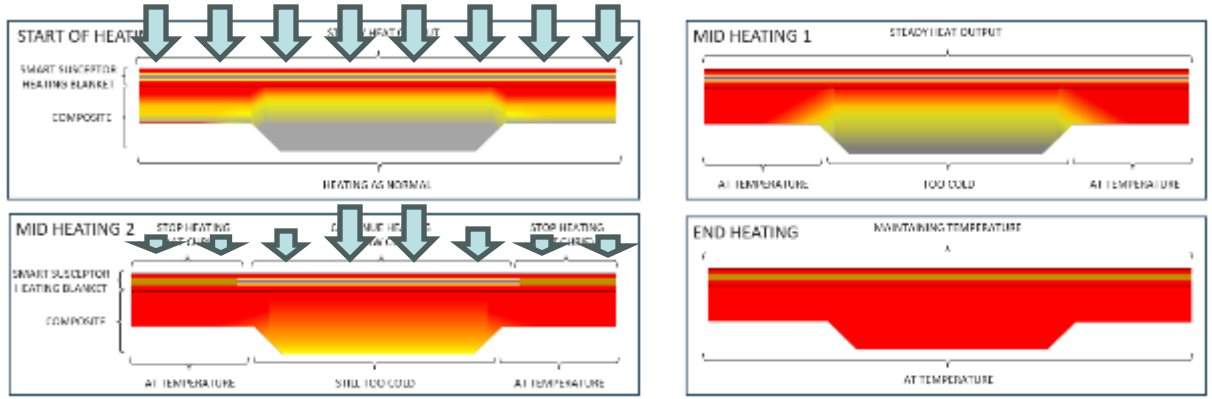
PROBLEM STATEMENT



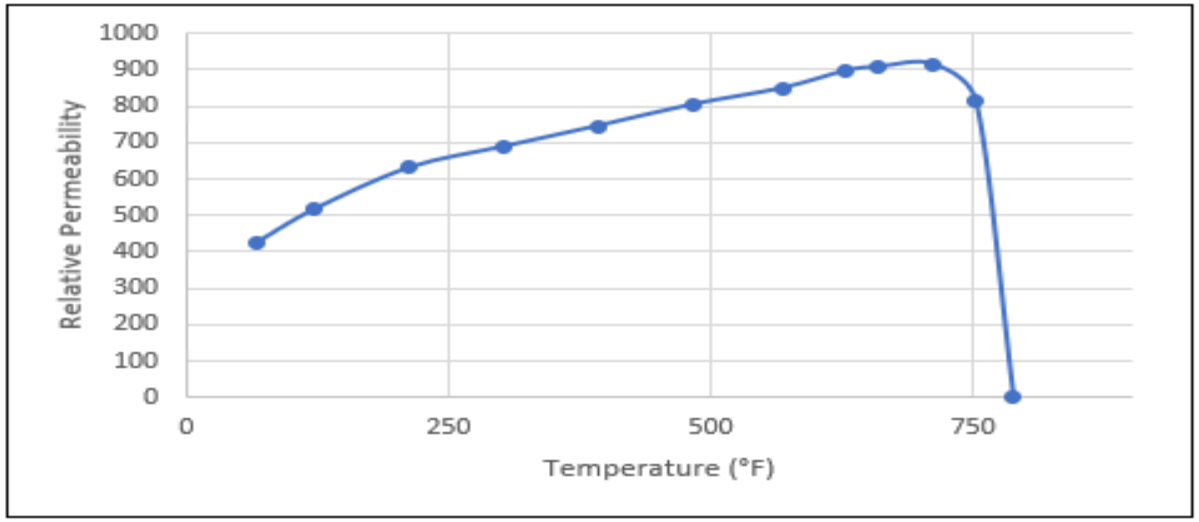
Using traditional resistance heating, even heat input into the top of the part results in uneven heating when the part thickness varies

SOLUTION STATEMENT

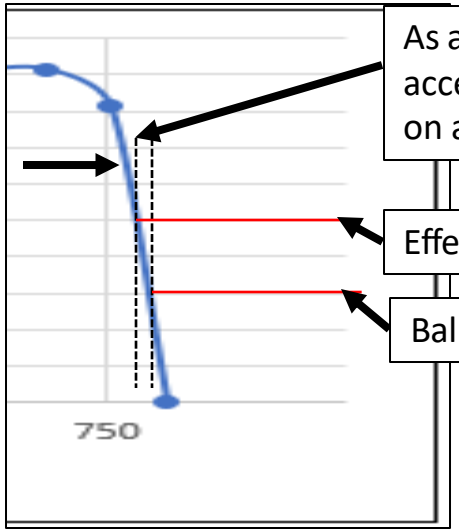


This is solved because once the heating elements reach its designated temperature, the smart susceptor becomes non-magnetic and stops excepting magnetic flux

The details on how this solution works



Typical heating curve at selected a selected field strength and frequency



As a coil turns heats and permeability falls, it accepts less and less of the magnetic field available on a turn by turn basis

Effect of coils accepting additional flux **(heat sink)**

Balance between BTU in and BTU's out of process

TECHNOLOGY SOLUTION – Smart Susceptors used in different processing configurations

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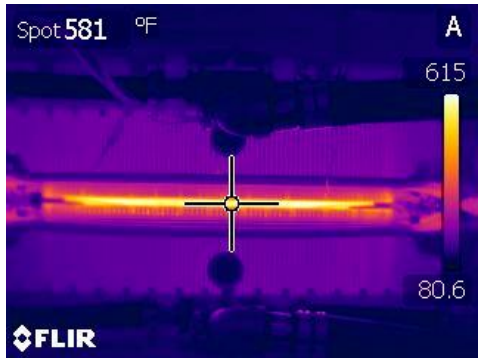
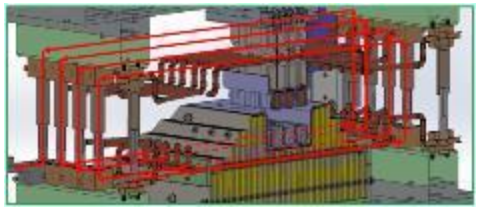
High Volume
(Thermoplastic or Thermoset)



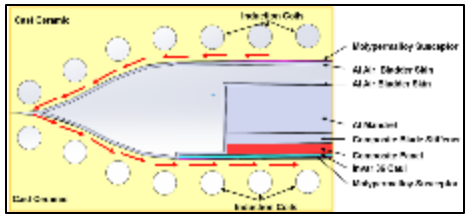
Matched metal die non-looped condition.



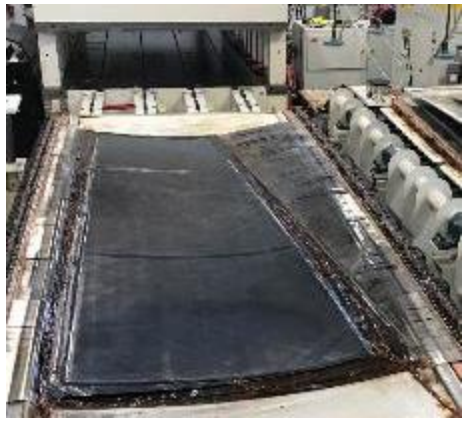
Induction heating field is established by the coil path, and the susceptors are independently configured and independently heated in the same field

Speeds up to 1000 deg / min Heat-up and 200 deg / min cooldown

Low Volume

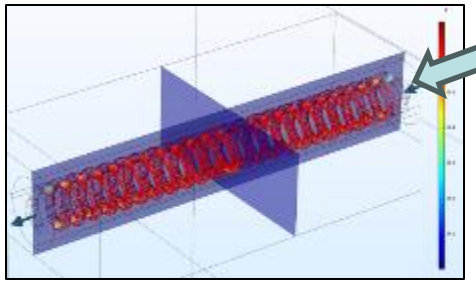


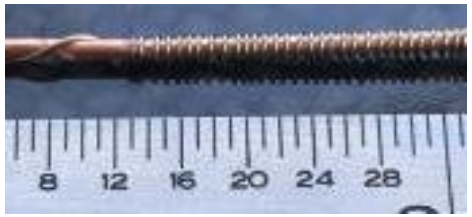
Air bladder die - looped condition. The induction path is looped around the part being heated.



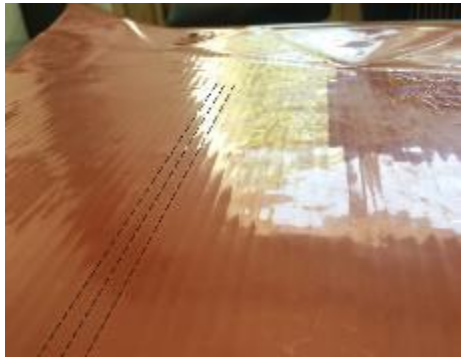
5 FEET X 15 FEET

Blankets





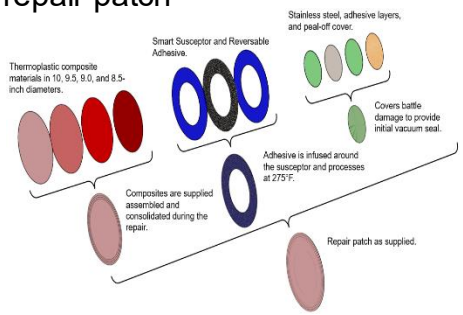
Wound Smart Susceptor wire around a Litz wire, used in heating blankets for debulking, bonding, co-bonding, and preheating steel structures for traditional fusion welding

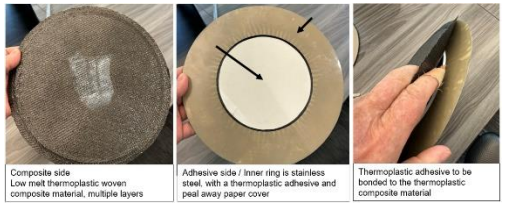


Welding / Repair

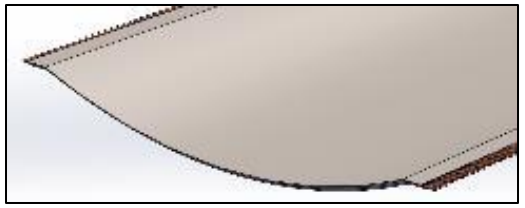
Smart Susceptor wires are embedded into resin and welded using an induction heating field

10 minute repair patch

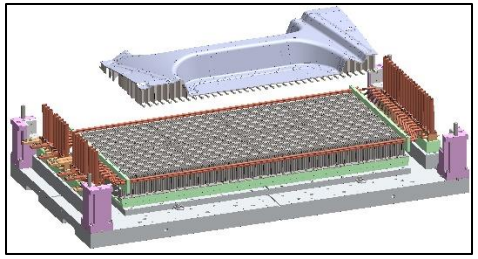




OoA tooling



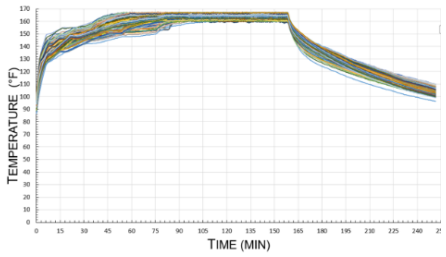
Direct heating of the backside of OoA Tooling

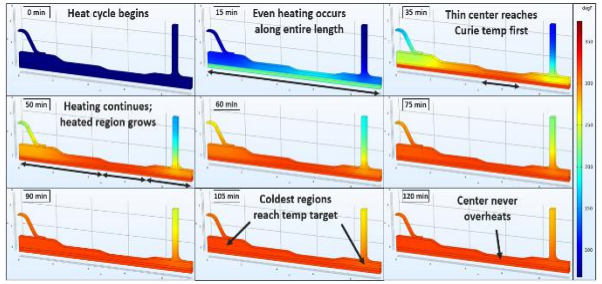


Quick swap tooling inserts

Why change?

- Temperature accuracy ± 6 °F
- Reliable and physically cannot overheat (even if all TC's are disconnected)
- Less expensive - consumables from $1,600/part to $20/part (Electrical and Gas costs)
- Better quality - blemishes reduced to 0%
- Effective heat sinks are eliminated





Temper's debulking system shown installed at Boeings West Jordon Facility in the fabrication of 787 rear elevators

Under construction at Temper's facility

Top view of debulking system

Applications (to us the world is full of nails)

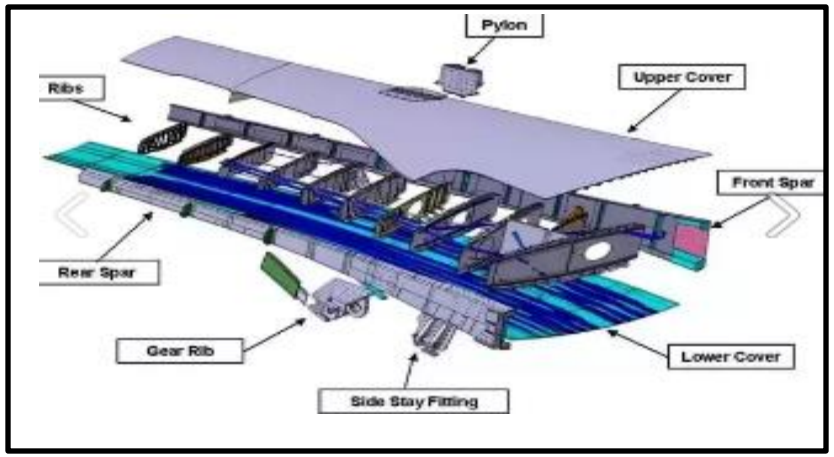
Temper Inc

Sikorsky- Raider X
- New thermoplastic aircraft

ALFA-S Drone
- Rapid manufacturing

Legacy Aircraft (e.g. A-10)
- Parts for MRO operations

Commercial aircraft
- Blocker doors



Commercial aircraft
- Wing components

Commercial aircraft
- Structural Repair

Questions?