Enhancing Heat Transfer Performance and Oxidation Resistance of Near Surface Cooling Channels using Additive Manufacturing Technologies

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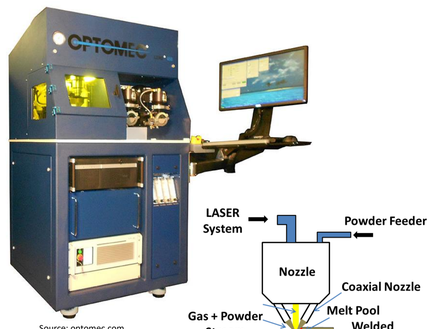
Introduction

With a target to push gas turbine efficiencies to 65%, the turbine inlet temperature is set to exceed 1700° C. As a result, there is a need to provide enhanced cooling and oxidation protection to the hot gas path components to ensure they are within their operational envelope. Additive manufacturing technologies provide unique opportunity to explore complex design spaces which can meet these challenges.

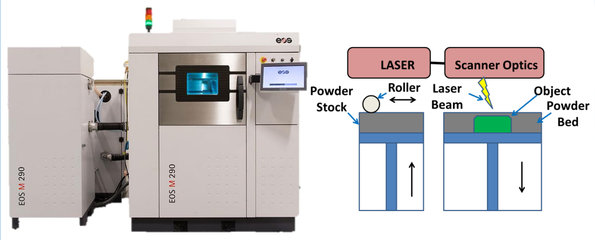
There are two parts of the current research effort:

- To provide uniform and highly augmented heat transfer using novel wall jet and lattice geometries in conjunction with near surface cooling channels (NSCC) fabricated through additive manufacturing (AM).
- To enhance oxidation resistance of hot gas path components by using oxide dispersion strengthened(ODS) powder for fabrication.

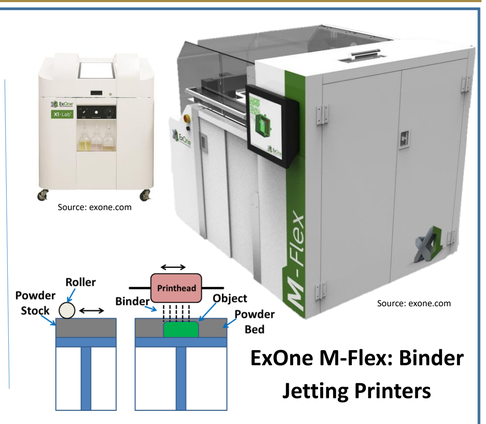
Additive Manufacturing



LENS450: Direct Metal Deposition (DMD)

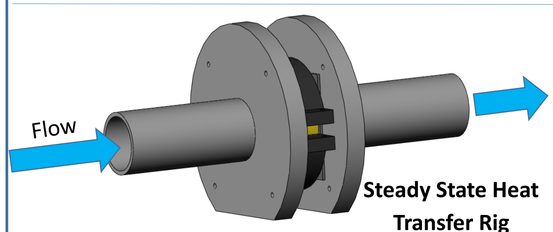


EOSM290: Direct Metal Laser Sintering (DMLS)

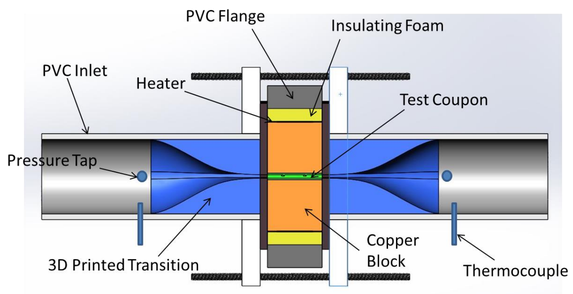


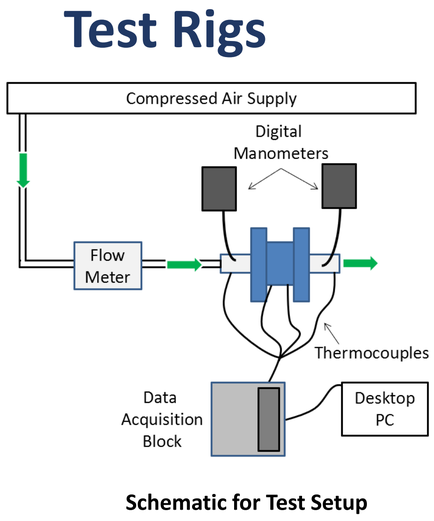
ExOne M-Flex: Binder Jetting Printers

Test Rigs



Steady State Heat Transfer Rig

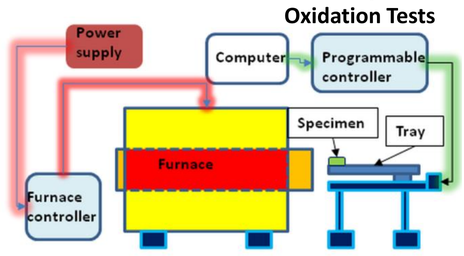




Schematic for Test Setup

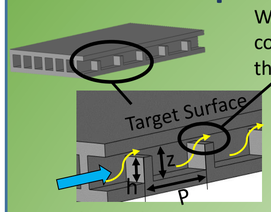
Zeiss Sigma 500 VP SEM

Thermal Cyclic and Oxidation Tests



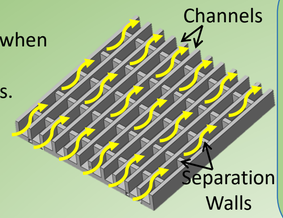
Test Coupons

Wall Jet Coupons



Channel parameters

Wall jet formed when coolant passes through the slots.

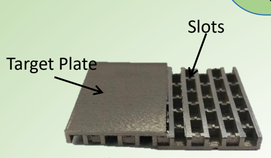


Features

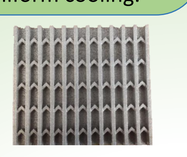
- Coolant flows through the slots and forms wall jets.
- Low temperature and high speed flow located near target surface provides uniform cooling.

Important parameters

Jet hydraulic diameter	D
Channel hydraulic diameter	D_{ch}
Jet pitch	P = 5D -11D
Number of jets	N = 4 - 6
Channel diameter	D_{ch}= 2.5D
Blockage ratio (h/Z)	BR = 0.5 – 0.75

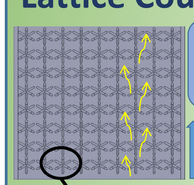


Slot type jets



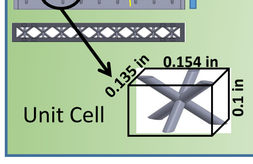
Chevron type jets

Lattice Coupons

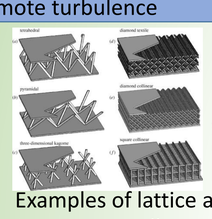


Features

- High surface area for heat transfer
- Promote turbulence



Unit Cell

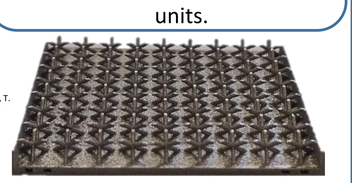


Source: Lu, T. J., Xu, F., Wen, T. "Thermo-Fluid Behaviour of Periodic Cellular Metals

Examples of lattice and unit cells

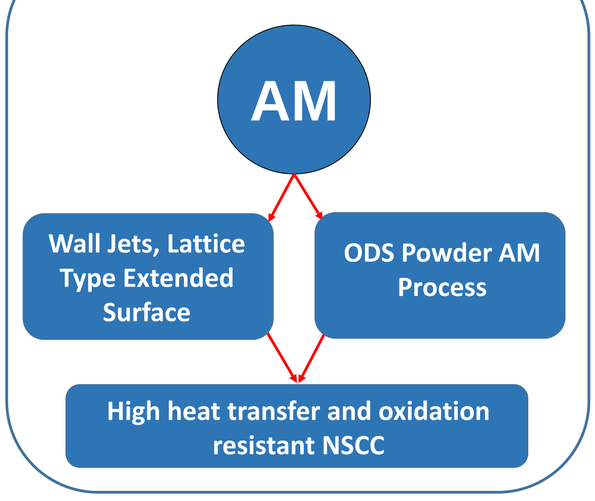
(a) (b)

Connectivity: (a) **Lcase1**: isolated units (b) **Lcase2**: interconnected units.

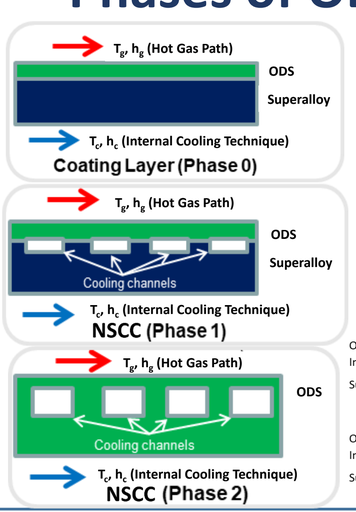


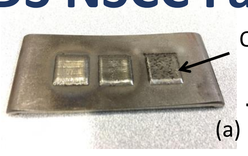
Lcase1 coupon with isolated units.

Overview



Phases of ODS NSCC Fabrication



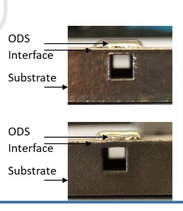


ODS deposited on superalloy using LENS 450

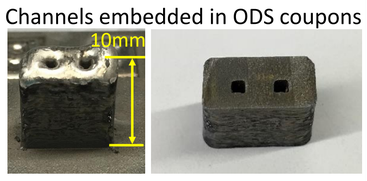
(a)

(b)

ODS on Inconel substrate
(a) Without channels
(b) With channels

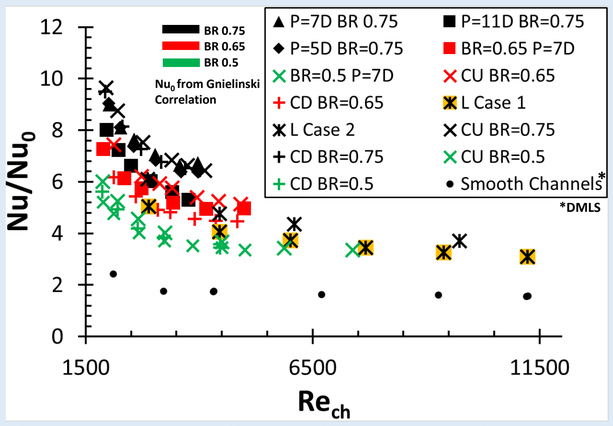


Channels embedded in ODS coupons



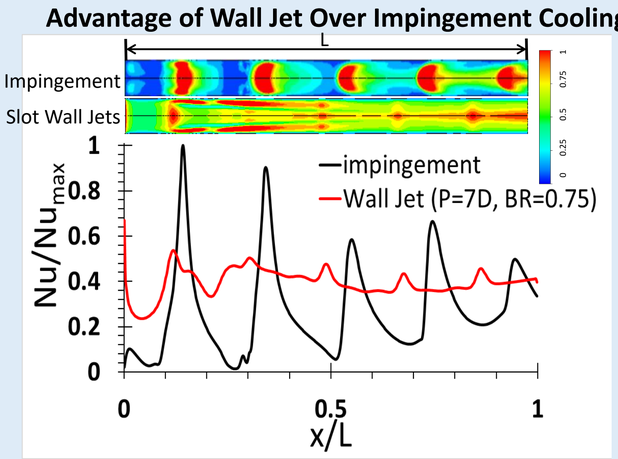
Heat Transfer

Comparison Between Different Geometries



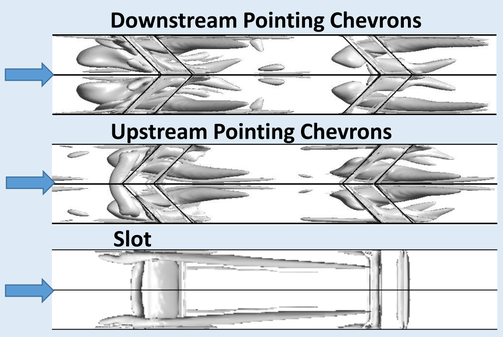
High Nu enhancement for AM printed coupons with wall jets and lattice geometries. Heat transfer increased with increasing BR and decreasing P for wall jet coupons.

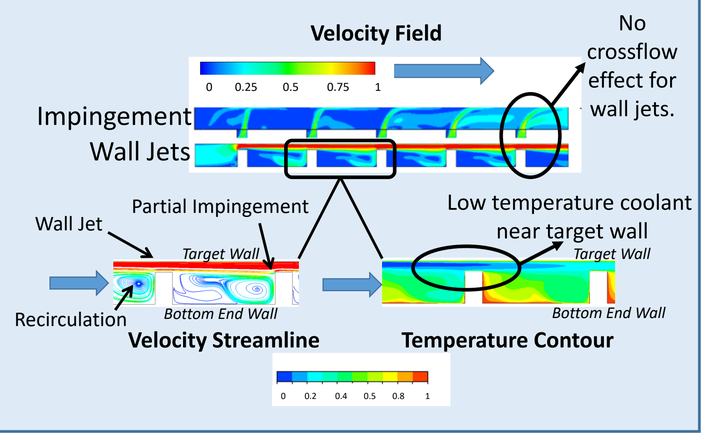
Advantage of Wall Jet Over Impingement Cooling



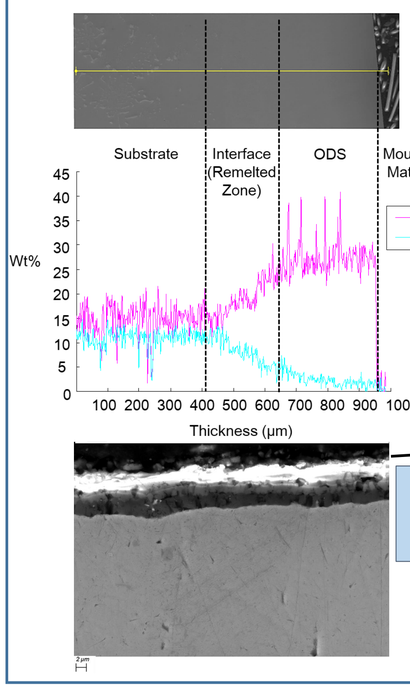
Spanwise averaged Nu/Nu_{max} for channel with wall jets and normally impinging jets at channel Re = 3000. Wall jets have much higher uniformity across target plate.

Enhancement in Chevron Wall Jets with Streamwise Vortices



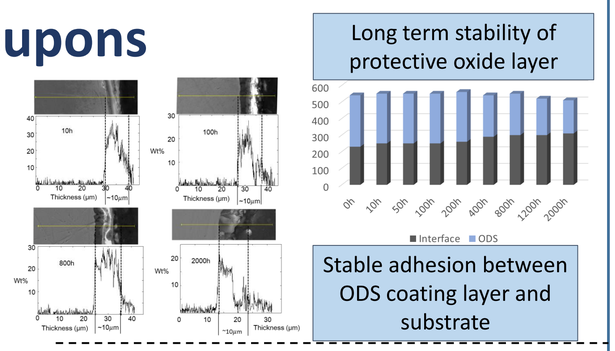


Oxidation Characterization of AM printed ODS Coupons

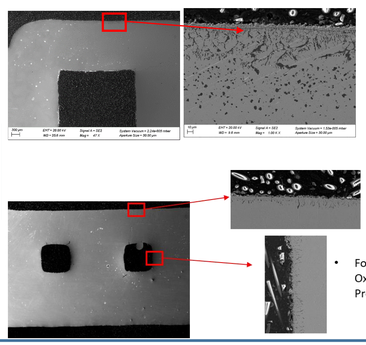


Continuous Al_2O_3 layer formation

Long term stability of protective oxide layer



Stable adhesion between ODS coating layer and substrate



Ongoing research work showed the formation process of protective oxide layer for both inner side and outer side of ODS channels.

- Formation of Oxide Layer in Progress

Future Work

- Explore new wall jet and lattice geometries.
- Fabricate lattice and wall jet coupons with ODS.
- Conduct high temperature tests on ODS coupons.