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Optimization of Machine Gun Barrels Using Additive Manufacturing

Presented at:
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Fredericksburg, VA
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Agenda

- Background
- Purpose
- Overview of Processes
  - Cold Spray
  - Wire Arc Additive Manufacturing (WAAM)
- Benefits and Drawbacks
  - Cold Spray
  - WAAM
- Application to Machine Gun Barrels
- Modeling and Simulation
- Barrel Designs – First Iteration
- Planned Testing
- Path Forward
- Questions

Background

- What is the problem?
  - Barrel temperature rises during firing
    - Potential for cook off, increased dispersion, catastrophic failure, premature barrel wear
  - Field Manual - ***FM 3-22.68 Crew Served Machine Guns***
    - Instructs Users on the operation, maintenance, and employment of crew served weapons
    - Requires barrel changes at prescribed intervals based on firing schedule
    - Machine Gun Crews must carry spare barrels

- What is the need?
  - Development of technologies that can eliminate the need for a spare barrel, thereby:
    - Reducing Soldier's Load
    - Reducing logistics burden
    - Keeping Soldier in the fight longer

Purpose

- *The purpose of the project is to develop and apply existing additive manufacturing processes to machine gun barrel fabrication, optimizing the characteristics of machine gun barrel characteristics and designs in an effort to minimize the need to change barrels and eventually eliminate the need to carry a spare barrel.*

  - Reduce chamber temperature
  - Reduce barrel overall temperature
  - Increase rounds to cookoff – minimize or eliminate possibility of cookoff in rapid firing schedule
  - Maintain dispersion and accuracy
  - Little to no increase in sub-assembly weight

Manufacturing Processes Investigated

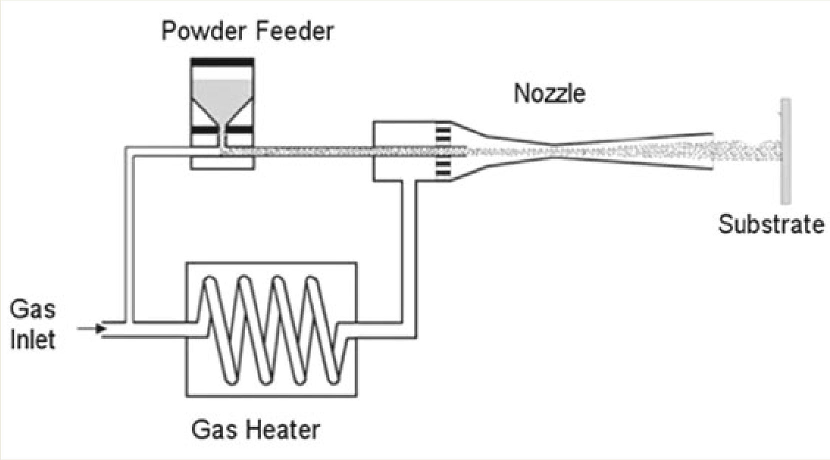
Cold Spray Deposition

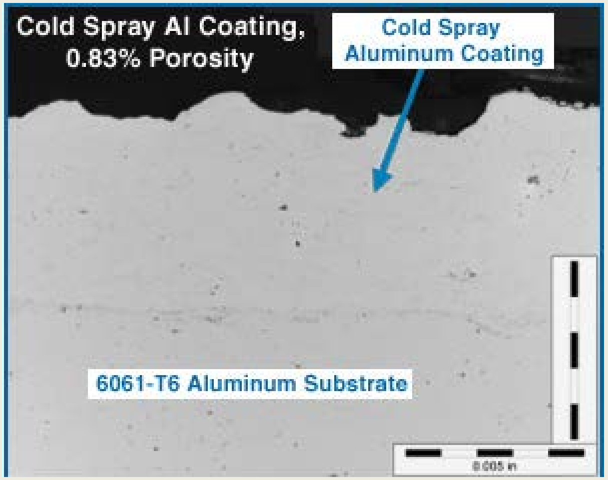
- Raw materials are supplied as powders
- A high pressure system is used to “spray” the powder onto a substrate surface at supersonic velocities
- When the particles hit the surface, they “pancake” and form microscopic mechanical bonds

Wire Arc Additive Manufacturing (WAAM)

- Raw materials are supplied in wire form
- Material is melted via wire arc, and laid down onto a substrate surface in a continuous bead (similar to a weld bead)
- Material cools and forms bond with substrate

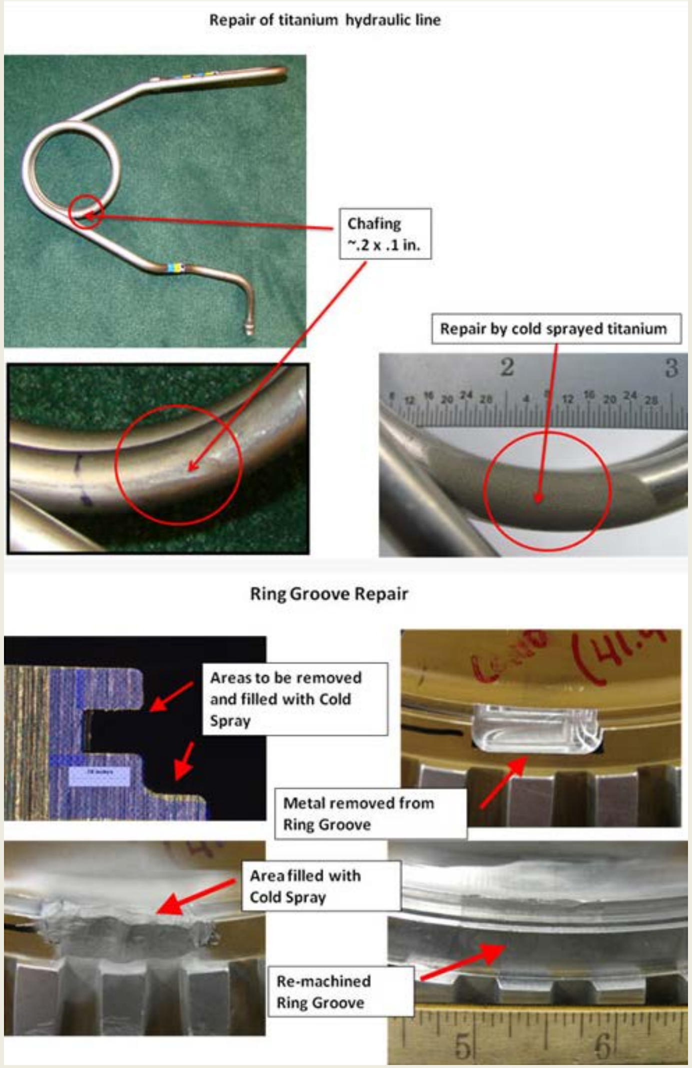
Cold Spray Deposition Process and Application





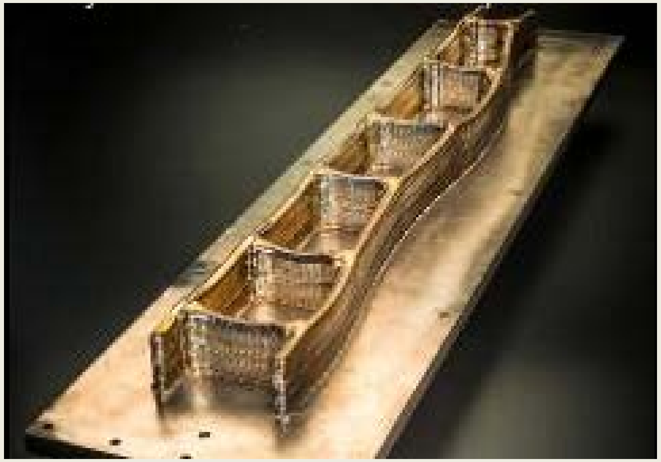
Images Courtesy of: ARL Center for Cold Spray

https://www.arl.army.mil



Wire Arc Additive Manufacturing (WAAM)

Courtesy of: http://waammat.com/about/waam



Courtesy of: http://www.3dprinterworld.com/article/metal-additive-manufacturing-impact-aviation

Benefits and Drawbacks

Cold Spray Deposition

- Benefits
  - Mechanical bonding at interfaces
  - Low temperature process – does not affect heat treat of substrate materials
  - Can apply metallic and non metallic materials
  - Can mix materials not typically available in alloys
- Drawbacks
  - In some cases the process can result in minimal porosity

Wire Arc Additive Manufacturing (WAAM)

- Benefits
  - Primarily useful for steels and aluminum alloys
  - Low cost, can use standard welding equipment in some cases
  - High deposition rates
- Drawbacks
  - High temperature process – could affect heat treated substrates

Application to Machine Gun Barrels

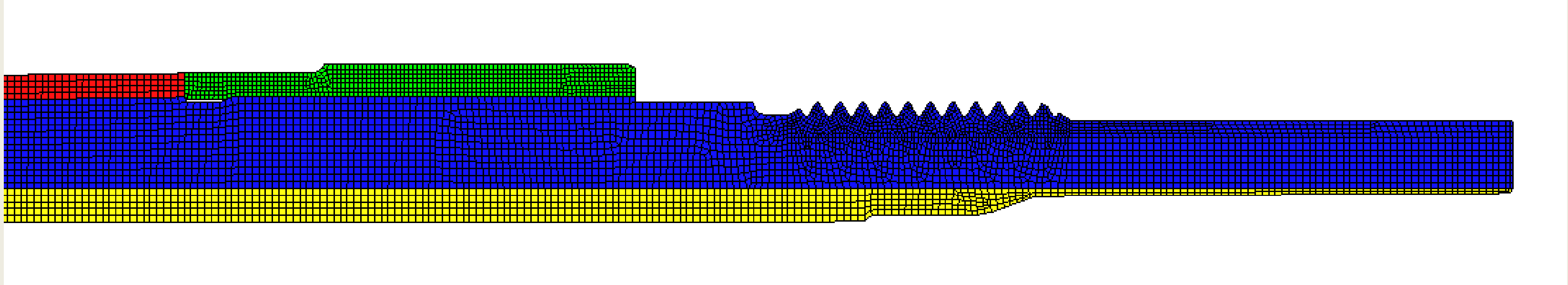
- Considerations
  - Thermal behavior of the system
    - Conduction – heat transfer through barrel wall
    - Convection – heat transfer to the environment (geometry)
    - Radiation – dominates at high temp
    - Thermal Capacity – material property that plays a major role in overall barrel temperature increase
  - Wear, barrel life, strength, accuracy and dispersion, weight, bulk
    - Must all be balanced with thermal performance

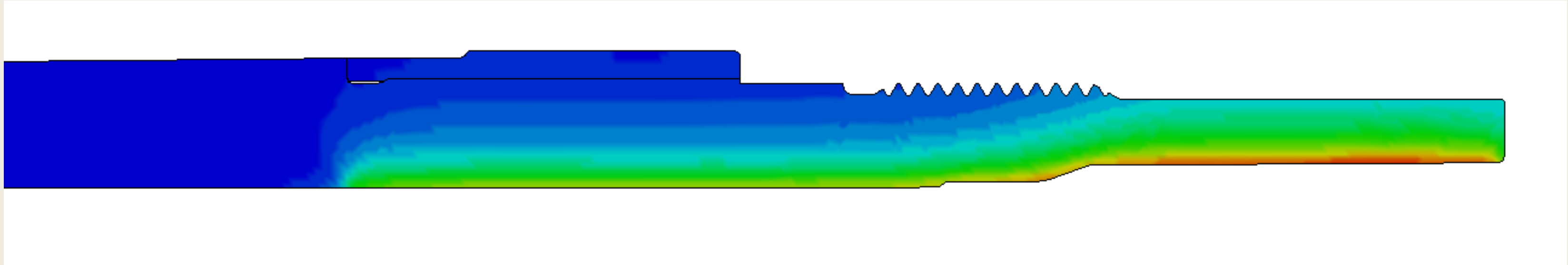
- Applications
  - Materials can be optimized for required performance, including non-traditional mixes that balance thermal and structural considerations
  - Mechanical bonding between layers permits multi-metallic barrels that balance thermal and structural considerations
  - High strength and wear resistant liners can be cold sprayed onto rifled sacrificial liners – rifle and line the barrel simultaneously
  - Structural material can be efficiently applied via WAAM, directly to liner
  - Liner and structural core can be heat treated prior to application of jacket
  - Jacket material and geometry can be optimized to minimize barrel temperature and promote heat transfer out of the barrel

Modeling and Simulation

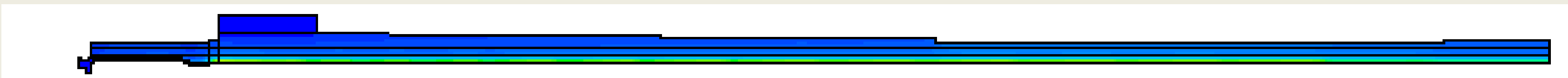
- **Structural Simulations**
  - Performed in LS-DYNA
  - Focused primarily on thickness of structural core
  - Results showed that the compressive stresses that dominate the response at the bore surface, primarily at the chamber and throat location, quickly subside as location moves radially
  - Liner primarily supports the compressive stresses, and the structural core primarily supports the hoop stress
- **Thermal Simulations**
  - Multiple layered barrel configurations were simulated in Fluent CFD software
  - Focus was optimization of material properties to reduce barrel temperature
  - Results showed:
    - Thermal conductivity of the materials played little role in reducing temperature
    - Heat capacity of the materials and overall thermal mass play a larger role in the overall net gain in barrel temperature
    - Convection to outside environment drives cooling rate at lower temperatures
    - Radiation drives cooling at higher temperatures

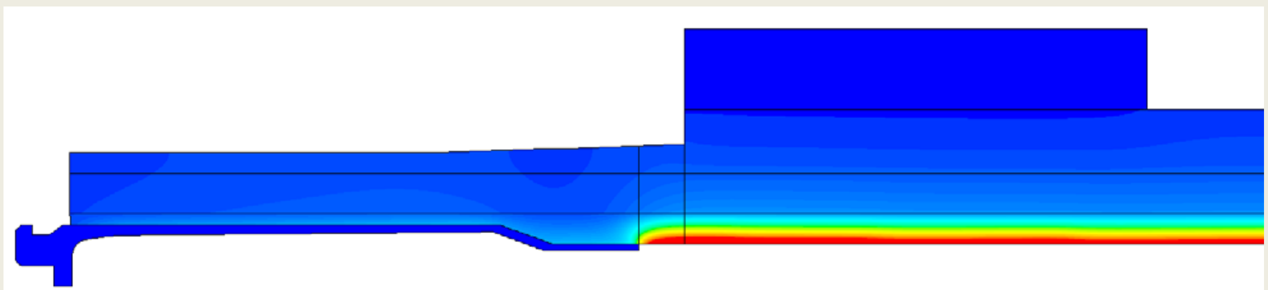
Structural Models





Thermal Models





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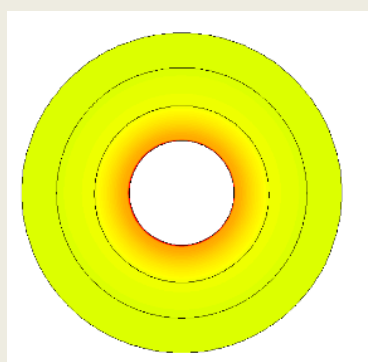

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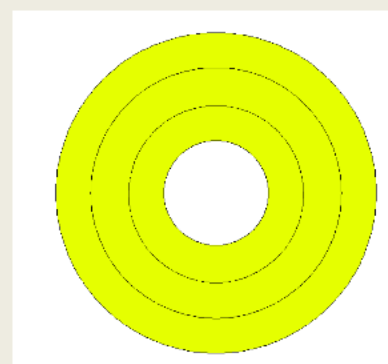
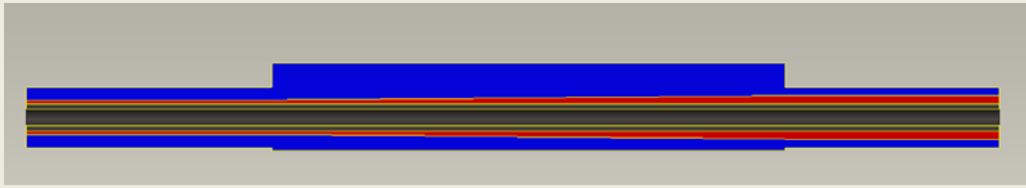


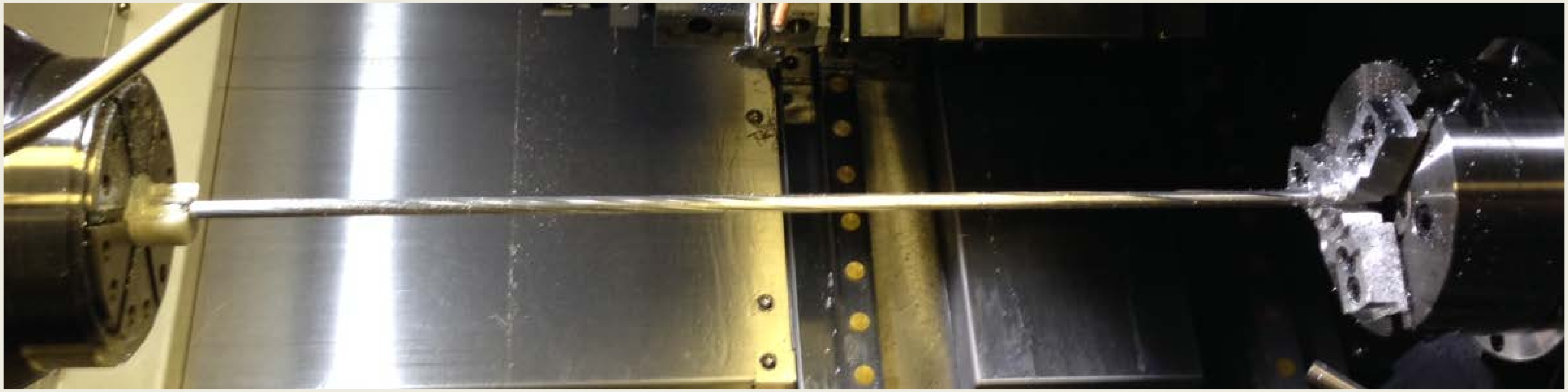
Barrel Design Considerations

- Cobalt Superalloy Liner – we know these are good with respect to wear, also play some role in minimizing heat into the barrel
- High Strength Core – minimize the thickness and weight of core
- High Heat Capacity Jacket – maximize volume/mass
  - Reduces overall temperature increase per unit of heat into the barrel
- Optimize outer profile of barrel for increased convection
- Combination of these design attributes have the best overall chance in reducing or eliminating the need for spare barrel

Barrel Designs



- Three layer barrel designs
  1. Liner
     - Cobalt superalloy (Cold Spray)
  2. Structural Core
     - High strength steel (WAAM)
  3. Jacket
     - 3 different options to optimize thermal performance (Cold Spray)
- Manufacturing of liner is a key technology component
  - Externally rifled mandrel is machined out of sacrificial material
  - Liner is cold sprayed directly onto mandrel
  - Mandrel is dissolved away



Planned Testing

- Crawl – Walk – Run Approach
  - Crawl – Characterize barrels
    - Does the liner have smooth enough surface?
    - Do the layers bond as intended?
    - Is there porosity?
    - Does the process produce sufficiently straight barrels?
  - Walk – Single shots
    - Possibly start with downloaded rounds
    - Fire single shots with fully loaded rounds
  - Run – Burst and aggressive firing
    - Sustained Rate
    - Rapid Rate
    - Possible cook-off testing

Path Forward

- Lessons learned from this phase will define future phases
- Future phases to include further refinement of designs and manufacturing processes to optimize barrels
- Potential for long term testing and possible endurance testing
- Possible MANTECH opportunities to develop the specific manufacturing techniques

Questions

Special thanks to the following individuals for their contributions to this project:

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