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Sandia National Laboratories

Evaluation of Thermal Spray Coatings and Shape Memory Alloys as Pressure Seals for Downhole Tools

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U.S. DEPARTMENT OF ENERGY | NNSA

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Overview

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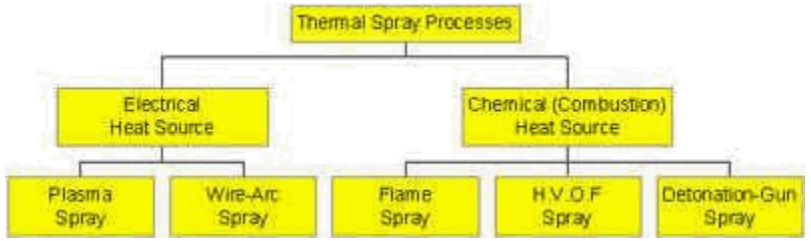
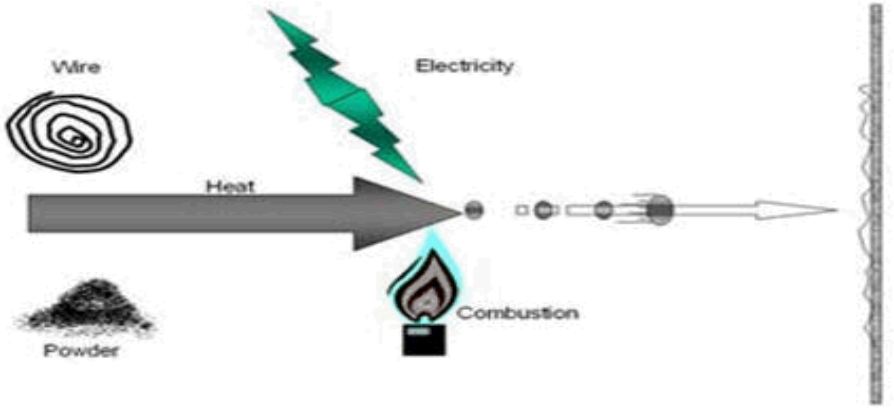
- Purpose: Research and test thermal spray coatings and shape memory alloys as an alternate pressure seal for tool joints
  - Thermal Spray Processes
    - Testing and Results
  - Shape Memory Alloys
    - Testing and Results

Thermal Spray Processes

- Electrical Heat Source
  - Plasma Spray
  - Wire-Arc Spray
- Chemical (Combustion) Heat Source
  - Flame Spray
  - HVOF Spray
  - Detonation-Gun Spray

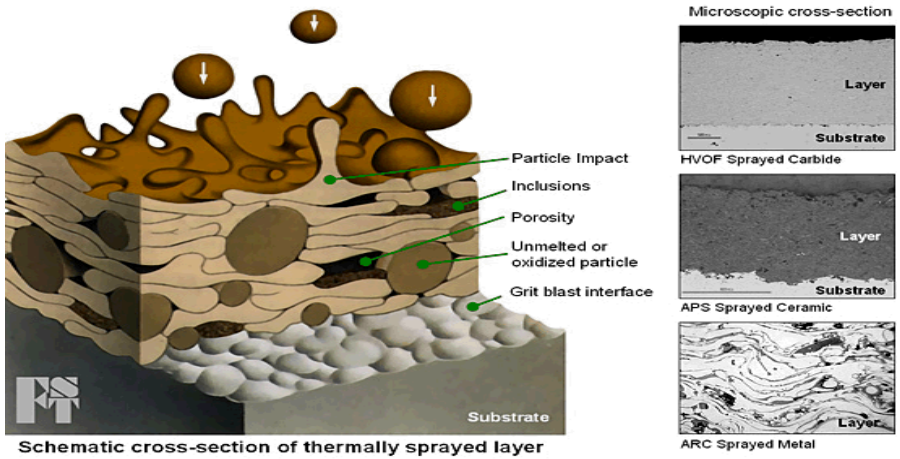




Thermal Spray Processes (Flame Spray Inc.)

Thermal Spray Deposits

- Characteristic properties of a thermal spray coating
  - Thin layers of molten coating material (splats)
  - Porosity
  - Oxide Inclusions
  - Unmelted or partially melted particles
  - Entrained air



Schematic cross-section of thermally sprayed layer (Flame Spray Technologies)

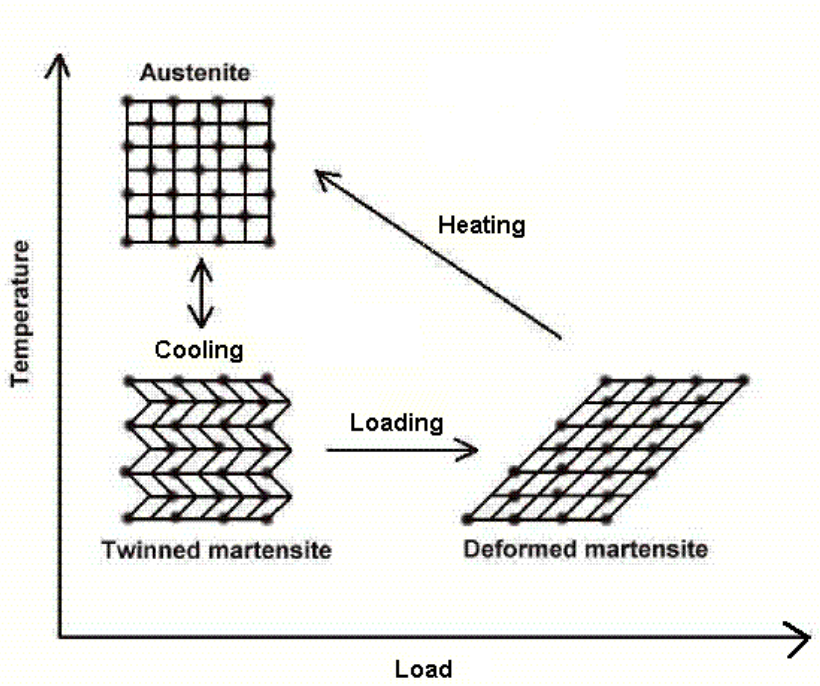
Thermal Spray Coatings

- Coating Materials and Processes
  - Selected by Sandia's Thermal Spray Department and Thermal Spray Solutions
  - Selection Criteria
    - Wear resistance
    - Corrosion resistance
    - Process adaptable to field application of coating

Coating Material	Process
Inconel (Ni 328)	HVOF
Metco 5803 (WC-Co)	HVOF
Ni Al	Twin Wire Arc Spray
Bondarc Wire-75B 95% Nickel/5% Aluminum	Twin Wire Arc Spray
Nickel Wire-06T 99% Nickel	Twin Wire Arc Spray
Moly Wire-13T 99% Molybdenum	Twin Wire Arc Spray
Stainless Steel-316L	Cold Spray
Colmonoy 69 SC 70% Nickel 17% Chromium	HVOF

NiTi Shape Memory Alloys (SMA)

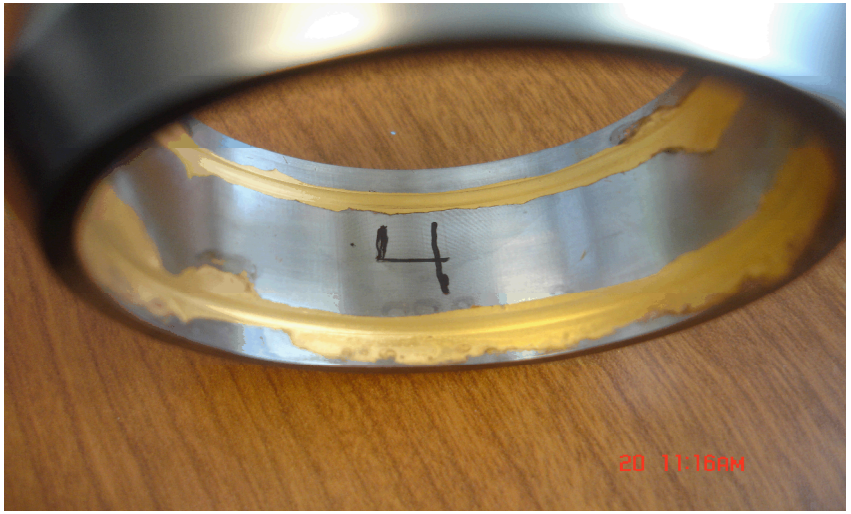
- Alloy Transformation Range
  - Alloy at room temperature is in the expanded state (Martensitic phase)
  - Transformation temperature 113 to 329°F (At 329°F the alloy is in the Austenitic phase)
  - Alloy returns to Martensitic phase at -148°F
- The NiTi alloys are able to withstand
  - Static loading
  - Fatigue
  - High temperature exposure
  - Thermal cycling
  - Good corrosion resistance



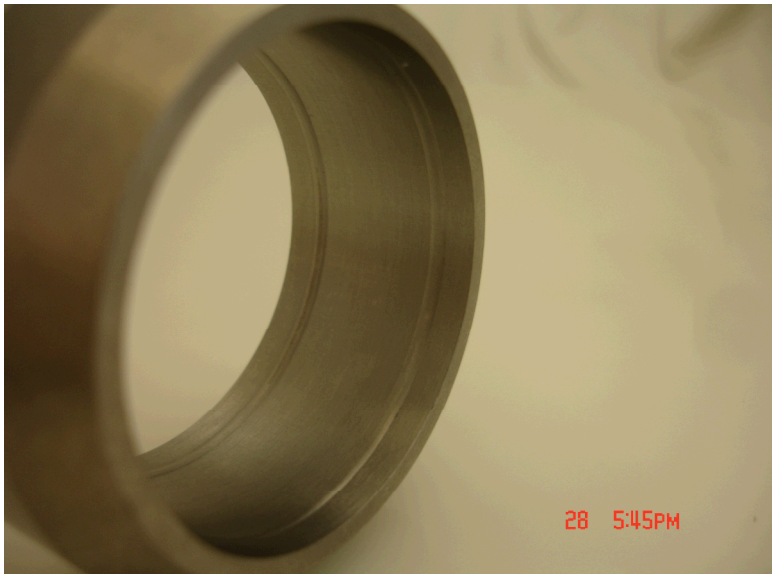
Microscopic Diagram of the Shape Memory Effect
(2001 SMA/MEMS Research Group)

Shape Memory Alloy Test Material

- Nickel/Titanium alloy
- Heat to Recover (HTR) Alloy
- Fully transformed at 329°F (165°C)
- Return to original (Martensitic phase) -148°F (-100°C)
- Clamping force (38,620 lbs)



SMA ring with gold plated ID



SMA ring with contact ridges

Seal Testing

- Test Configuration
  - 304L stainless steel 1 3/4”mock tools samples
  - Torqued to 25 ft-lbs
  - Weigh samples before testing
  - Pressure/Temperature test
    - 5,000 psi (345 bars)
    - 437°F (225°C)
  - Weigh samples after testing

1-3/4” mock tool sections

Test Results (Thermal Spray)

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Coating Material	Number of Samples	Pressure Test Results
Inconel (Ni 328)	8	2 samples passed all tests
Metco 5803 (WC-Co-Ni) 25% Nickel	4	1 sample passed all tests
Ni Al	4	All samples leaked
Bondarc Wire-75B 95% Nickel 5% Aluminum	4	All samples leaked
Nickel Wire-06T 99%Nickel	4	1 Sample passed all tests
Moly Wire-13T 99% Molybdenum	2	All samples leaked
Stainless Steel-316L	2	All samples leaked
Colmonoy 69 SC 70% Nickel 17% Chromium	2	1 Sample passed all tests
Ni Al bond coat Inconel (Ni 328) cover	4	1 sample passed all tests
Fused	1	Sample passed all tests
Sealed with Diamant	8	1 sample passed all tests. Leakage rate improved on samples that had previously leaked

Test Results (Shape Memory Alloy)

- 18 Mock Tools tested and 12 passed
- The mock tools that passed either had Teflon tape, lead tape, or gold plating between the ring and tool body

	Sample #	2A	2B	3A	3B	4A	4B	4C	6	7	2	3	4	5	6	10	16	17	18
1" mock tool		yes	yes	yes	yes	yes	yes	yes	yes	yes									
1-3/4" mock tool											yes	yes	yes	yes	yes	yes	yes	yes	yes
Smooth ID		yes	yes	yes	yes	yes	yes	yes	yes	yes									
Ridge on ring ID											yes	yes	yes	yes	yes	yes	yes	yes	yes
Gold Plating									yes		yes	yes		yes	yes		yes	yes	yes
Silver Plating							yes												
Teflon Tape					yes					yes									
Lead Tape			yes					yes											
Passed Pressure/Temp. Test			yes		yes				yes	yes	yes	yes	yes	yes	yes		yes	yes	yes
Failed Pressure/Temp. Test		yes		yes		yes	yes	yes								yes			

Conclusion (Thermal Spray)

- Considerable progress was made during this program and it is possible to create a pressure seal using thermal spray, but the results are too inconsistent to establish this process as a viable solution.
- Further investigation in a controlled spray environment could help reveal and eliminate the parameters leading to the inconsistent seal performance.

Conclusion (SMA)

- Test results show that SMA rings can be successfully used to seal tool joints and can also serve as an additional backup seal to both traditional o-rings and metal c-rings
- Gold Plating of the NiTi rings is difficult but can be done with proper etching and using cool chemical baths.
- Machining the rings is possible but precautions must be taken to keep the rings cool during the machining process
- One unique feature of the SMA rings is that the ring can be removed from the tool body by cooling
- The clamping force is based on the alloy size, shape and the gap distance between the ring and the substrate
- Additional research will be needed but there is equipment commercially available that can be used to install and remove the rings in the field.