# Solutions Flash
## Improved Surface Protection for Marine and Non-Marine Hydraulic Rods

SF-0030.1 – May 2023

## Today's Situation

Hydraulic cylinder rods are well-known in many industries as an effective method to move large, heavy loads. Critical to efficient actuation of the hydraulic cylinder rod is the surface finish of the piston rod, where consistently very low roughness and minimal to no waviness are musts. Surface imperfections as a result of corrosion and/or wear reduces the effectiveness of the rod and can eventually lead to seizure and failure.

As such, the hydraulic piston rod surfaces have traditionally been protected with hard chromium plating. However, the production of hexavalent chromium [Cr(VI)] during processing has lead to environment and safety concerns with tough restrictions imposed by government regulatory agencies. As a result, hard chromium plating costs are increasing and the number of hard chromium processors decreasing globally. This has caused many industries to seek alternative surface solutions to protect hydraulic cylinder rods that can meet the cost and performance requirements demanded by the market.

Hydraulic cylinders used in mining application such as subterranean roof supports (cover image), mining equipment actuators and other non-marine environments primarily use iron-based 431 stainless steel overlays applied by conventional laser cladding or ultra high-speed laser cladding (EHLA).

Large (3 to 20 m length) marine hydraulic cylinders used for offshore riser tensioners and other corrosive environment applications primarily use laser clad or EHLA overlays of nickel-based Inconel 625 or cobalt-based Ultimet.

The current iron- and nickel-based overlays are highly crack susceptible and normally require a costly preheating step. Even with preheating these legacy materials can crack easily during processing which leads to downtime and expensive rework. Clearly, new materials are needed that have a wide application window to eliminate cracking and the associated costly preheat. Further, these materials must provide better wear resistance to increase hydraulic cylinder operational life.

## Our Solution

Utilizing our unique Scoperta™ Rapid Alloy Development (RAD) technology, Metco Joining & Cladding has developed breakthrough solutions for protecting hydraulic cylinder rods from wear and corrosion that can be applied using standard laser cladding or EHLA processes. These solutions are optimized for different conditions — for example, operation in atmospheric (non-marine) versus marine environments. The materials have environmentally-friendly cobalt-free compositions.

The Metco 1020x series is an iron-based composition developed to protect hydraulic cylinder rods in non-marine environments. Overlays of Metco 1020x series offers corrosion resistance comparable to 431 stainless steel overlays.

Metco 1720x materials series are intended for the harsh corrosion environments that exist in marine applications. Overlays of Metco 1720x have corrosion resistance comparable to overlays of Inconel 625 or Ultimet.

Both Metco 1020x series and Metco 1720x series offer significantly improved abrasion resistance while avoiding the potential cracking issues of their traditional overlay counterparts. As a result, they can extend the service life of a hydraulic cylinder rod and reduce maintenance and replacement costs.

**Figure 1.** Non-marine hydraulic cylinder rod applications include those found on the bucket excavator and earth-moving truck bed lift mechanism. Metco 1020x series products are ideal for these applications

**Figure 2.** Marine hydraulic cylinder rod applications include platform riser tensioners and on-platform cranes. Metco 1720x series products are ideal for these applications

# Solution Description and Validation

## 1. Application Requirements for Hydraulic Cylinder Rods

Efficient functionality of hydraulic cylinder rods is dependent upon the surface quality of the rod. Therefore, protective surfaces should have the following characteristics:

- Corrosion resistance equivalent or better than:
  - 400-series stainless steel for non-marine applications
  - Inconel 625 or Ultimet for marine applications
- Crack-free / defect-free overlay
  - Applied in multiple layers
  - Eliminate the need to preheat when cladding

  **Note:** Many hardfacing materials do crack, which can lead to additional corrosion.
- Abrasion resistance
  - Overlay should provide both corrosion and abrasion resistance
  - Overlays must finish well to meet operating requirements
- Environment, health and safety concerns
  - Eliminate hard chromium plating and Cr(VI)
  - Avoid cobalt-based materials

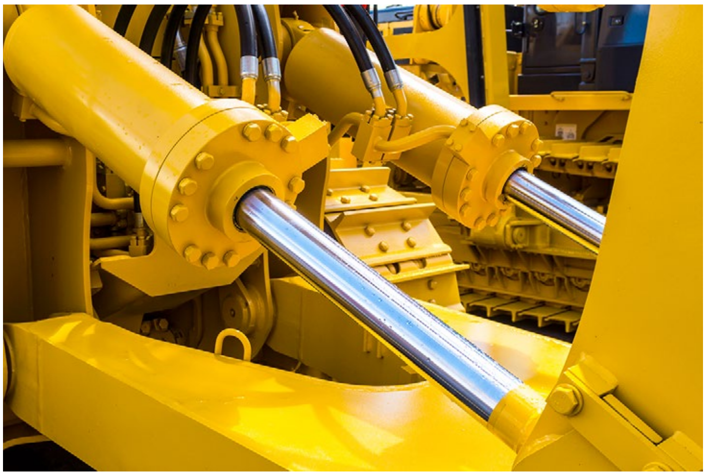


**Figure 3.** To maintain the operational efficiency of hydraulic cylinder rods, protective surfaces must meet stringent requirements.

## 2. The Benefit of Scoperta RAD

A unique and important part of our material R&D toolkit is our Scoperta Rapid Alloy Development process — a computational modeling aid that can quickly review tens of thousands of potential compositions and 'suggest' candidate compositions for further empirical analysis.

This approach is a proven method that often leads to material compositions with breakthrough service properties for the application under investigation. It was used in the development of both the non-marine and marine hydraulic rod materials discussed in this document.

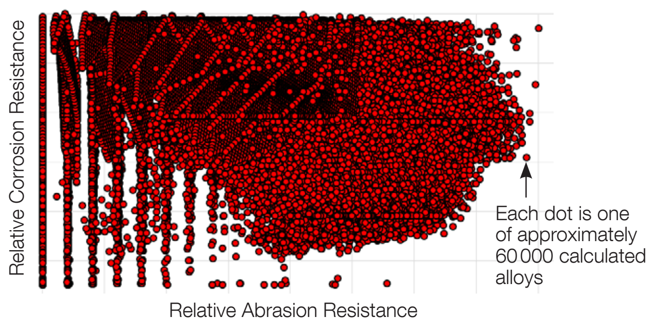



**Figure 4.** Rapid Alloy Development (RAD) Modeling enabled the design of new protective overlays for hydraulic rods in marine and non-marine applications.

## 3. Solutions for Non-Marine Hydraulic Rod Applications: Metco 1020x Series Materials

### 3.1 Design Intent and Properties of Metco 1020x Series

The Metco 1020x material series was developed to precipitate a small fraction of hard phase in a corrosion resistant matrix. The hard phase precipitates were engineered to form isolated morphologies that provide an increase in abrasion resistance and are not detrimental to the crack-resistance of the overlay. (Figure 5).

One of the unique properties of the Metco 1020x series is that overlays softer compared to 420 and 431 stainless steels, and a popular competitive overlay, but laboratory testing shows it is more abrasion resistant than those materials. (Figure 6). This contradiction in properties was one of the design intents of the Metco 1020x series.

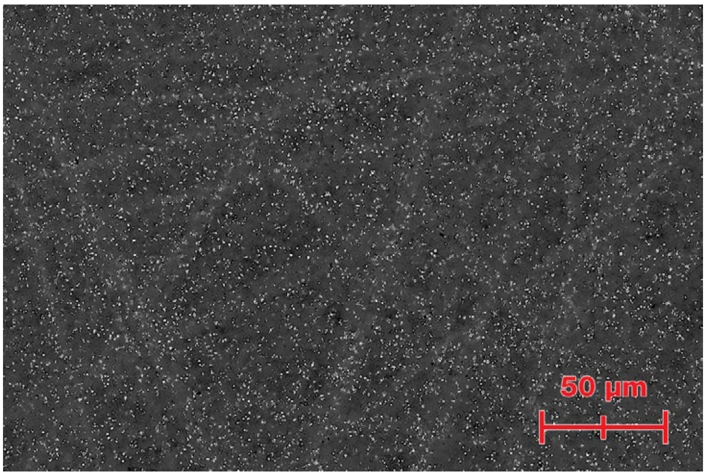
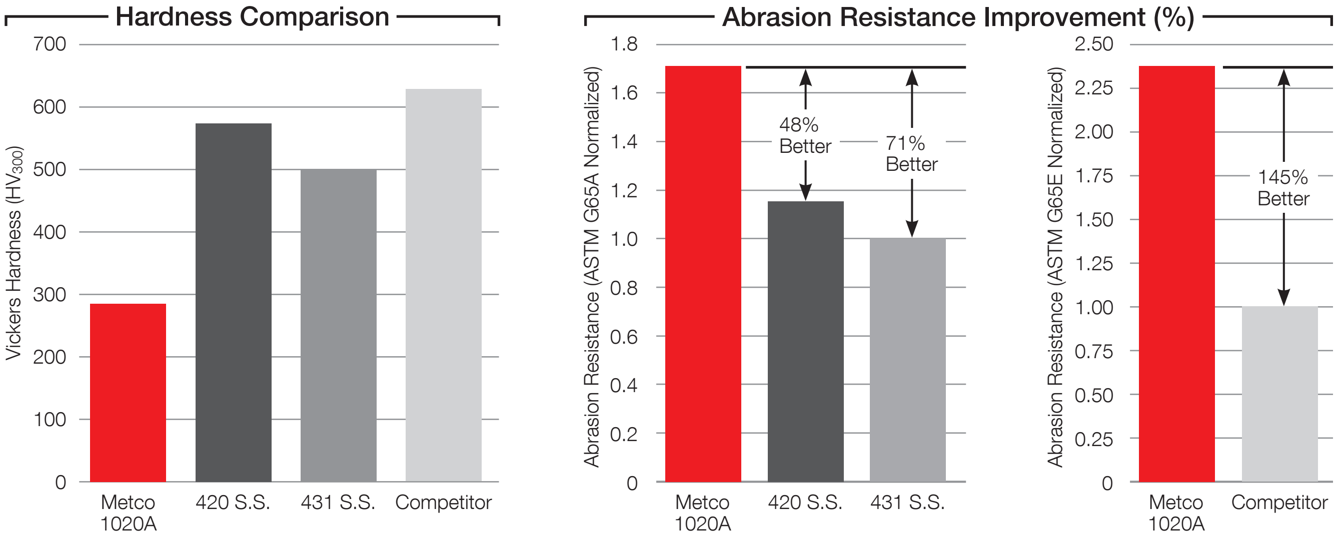



**Figure 5.** Typical microstructure of an overlay produced with Metco 1020A using a conventional laser cladding process..




| Overlay Alloy | Hardness | Normalized Abrasion Resistance | | Improvement Using Metco 1020A Overlay |
|---|---|---|---|---|
| | | ASTM G65A | ASTM G65E | |
| Metco 1020A | 285 $HV_{300}$ | 1.71 | 2.45 | --- |
| 420 Stainless Steel | 570 $HV_{300}$ | 1.15 | --- | ≈ 48 % |
| 431 Stainless Steel | 500 $HV_{300}$ | 1.00 | --- | ≈ 71 % |
| Competitor | 620 $HV_{300}$ | --- | 1.00 | ≈ 145 % |

**Figure 6.** Comparison of hardness and abrasion resistance for non-marine protective overlays. While Metco 1020A overlays are softer than the stainless steel and a popular competitive overlays, it clearly has significantly better abrasion resistance. Note: Abrasion resistance is based on normalized volume loss where higher numbers in the graph are better.

Two versions of Metco 1020x are available that have been designed for different processes, as shown in the Table 1.

| Product Name | Particle Size Dist. | Process |
|---|---|---|
| Metco 1020A | -150 +53 µm | LC, PTA |
| Metco 1020B | -53 +20 µm | EHLA |

**Table 1.** Available Metco 1020x series products.
**LC** = Conventional Laser Cladding; **PTA** = Plasma Transferred Arc Welding;
**EHLA** = Ultra High-Speed Laser Cladding

- Proprietary iron-based alloy developed using Scoperta RAD
- Patent pending
- Manufactured in-house by Metco Joining & Cladding using gas atomization
- Spherical powder particles of consistent chemical composition
- Similar overlay properties are produced using either conventional laser cladding or ultra high-speed laser cladding
- Overlays exhibit corrosion resistance similar to 431stainless steel
- Overlays exhibit lower hardness but improved abrasion resistance compared to 431 stainless steel

### 3.2 Modeling Stable Matrix Phases

A tool that can be used to predict the matrix phase in iron-based alloys is the Schaeffler Diagram (Figure 7). By simply calculating the chromium equivalent and nickel equivalent of the alloy based on its composition, one can use the Schaeffler diagram to predict not only which phase(s) form but also estimate the relative volume fraction of the phase(s).

As shown on the Schaeffler diagram, the normal compositional tolerances in 431 stainless steel can form any combination of martensite, austenite, and ferrite phases. Each phase possesses different properties which contribute to the known problems of cracking and hardness variations in 431stainless steel overlays. To avoid this issue, the Metco 1020x series of materials was designed to form a 100% ferritic matrix phase as shown in the bottom right portion of the Schaeffler diagram. Although ferrite is fairly soft and results in low overlay hardness, it allows for a wide application window and consistent properties in the coating.

To overcome the low hardness of ferrite, the material was engineered to precipitate hard phases that improve the abrasion resistance of the overlay. The hard phases are engineered to form small isolated precipitates and are subsequently not detrimental to the crack susceptibility of the material.

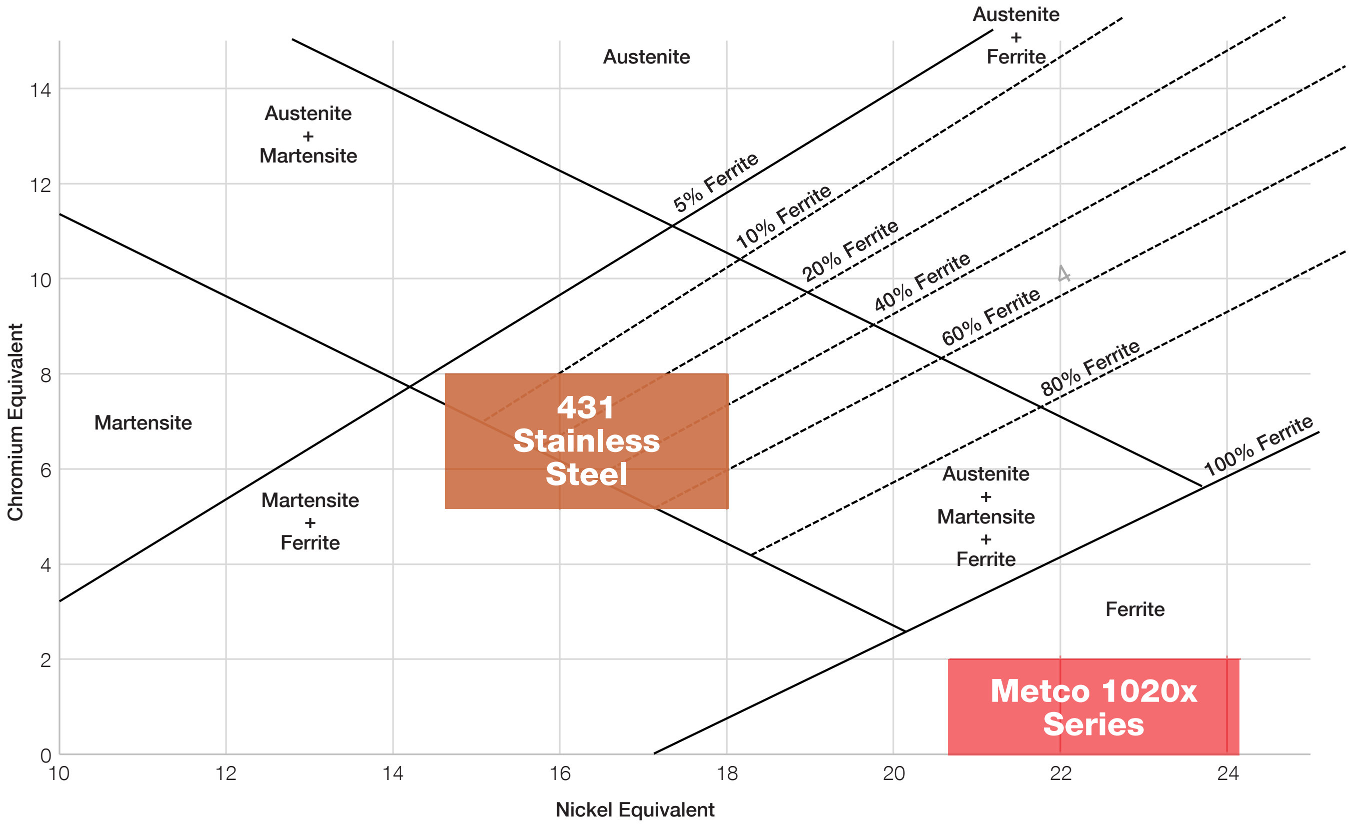



**Figure 7.** Schaeffler diagram used to model stable iron matrix phases. 431 stainless steel can form different matrix phases and volume fractions of those phases based on composition tolerance and processing parameters. In contrast, Metco 1020x materials form a stable matrix allowing for a wide application window and consistent overlay properties.

## 3.3 Corrosion Resistance

The corrosion resistance of overlays of Metco 1020 and 431 Stainless were tested via ASTM B117, ASTM G59 and ASTM G61. As shown in Table 2, Metco 1020x overlays demonstrated a performance similar to 431 stainless steel in all laboratory tests. Based on these results it can be concluded that overlays of Metco 1020x are at least as corrosion resistant as 431 stainless steel overlays for these conditions.

| Overlay Alloy | ASTM B117 Salt Spray Test (1000 h) | ASTM G59/G61 (< 0.01 mpy) | |
|---|---|---|---|
| | | Tafel Extrapolation | Linear Polarization |
| Metco 1020x | Pass | Pass | Pass |
| 431 S.S. | Pass | Pass | Pass |

**Table 2.** Corrosion testing comparing overlays of Metco 1020x and 431 stainless steel

## 3.4 Finishing of Metco 1020x Series Overlays

Metco 1020B, clad via EHLA, finishes to customer standards when using grinding processes. Metco 1020x series overlays have been successfully clad crack-free in all laser cladding trials without the need for preheating.

**Figure 8.** Grinding a hydraulic rod to a high finish.

## 3.5 Summary: Metco 1020x Series

In conclusion, Metco 1020x overlays exhibit a wide application window for producing a crack-free coating that has comparable corrosion resistance to 400 series stainless steels and is more abrasion resistant than traditional 400 series stainless steels.

## 4. Solutions for Marine Hydraulic Rod Applications: Metco 1720x Series Materials

### 4.1 Design Intent and Properties of Metco 1720x Series

Using a design strategy similar to that of the Metco 1020x material series, overlays of Metco 1720x material series was developed to exhibit higher abrasion resistance than traditional Inconel 625 or Ultimet overlays while maintaining a crack-free coating that has similar corrosion resistance in marine environments.

The key to this design is the precipitation of isolated hard phases in a nickel-based, corrosion-resistant matrix (Figure 9). The introduction of the hard phases increases the abrasion resistance, but since the hard phases form an isolated morphology, they are not detrimental to the crack-resistance of the overlay.

These precipitates increase the hardness of the overlay relative to the incumbent materials as measured by Vickers Hardness indentation (hardness graph) which then translates to an increase in abrasion resistance as measured by ASTM G65-A (Figure 10).

Two versions of Metco 1720x are available that have been designed for different processes, as shown in the Table 3.

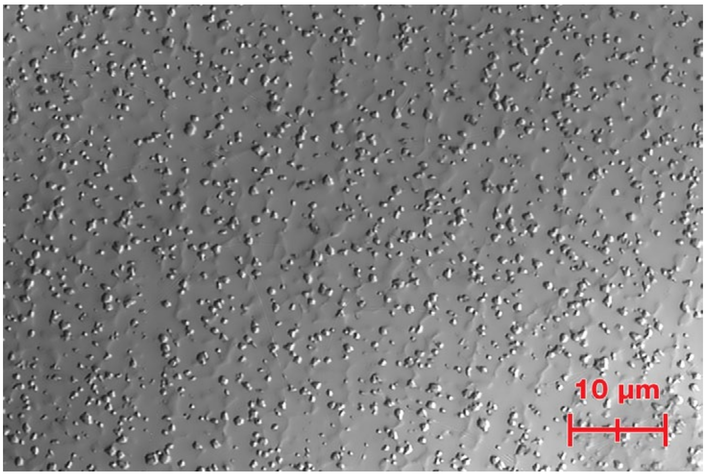
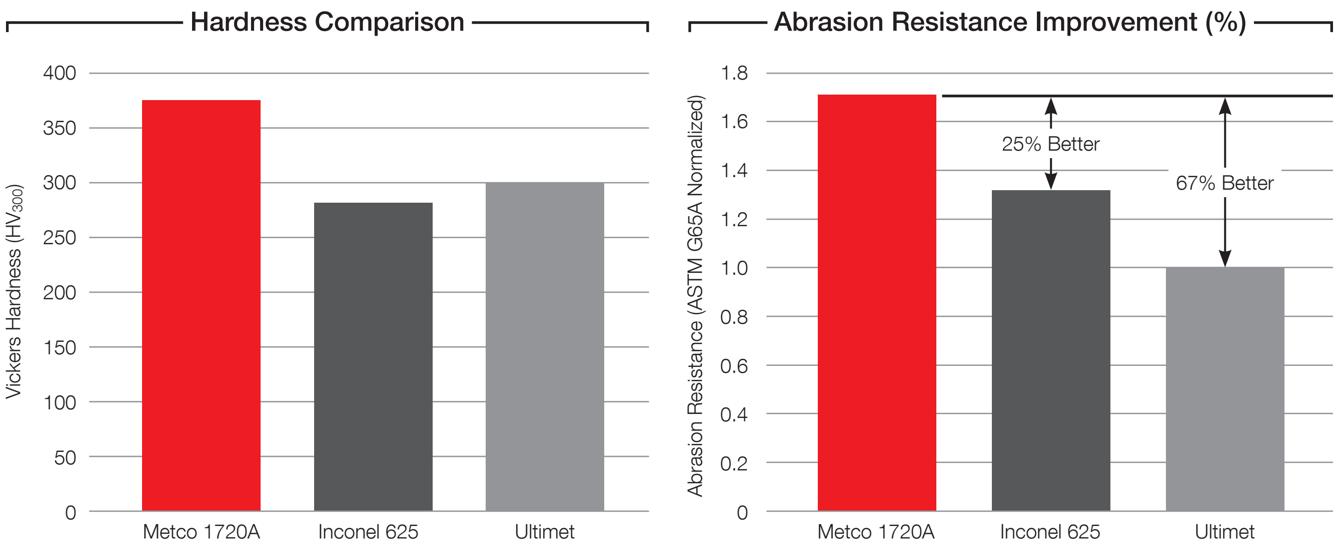



**Figure 9.** Typical microstructure of an overlay produced with Metco 1720A using a conventional laser cladding process..

| Product Name | Particle Size Dist. | Process |
|---|---|---|
| Metco 1720A | -150 +53 µm | LC, PTA |
| Metco 1720B | -53 +20 µm | EHLA |

**Table 3.** Available Metco 1720x series products.
**LC** = Conventional Laser Cladding; **PTA** = Plasma Transferred Arc Welding; **EHLA** = High-Speed Laser Cladding




| Overlay Alloy | Hardness | Normalized Abrasion Resistance ASTM G65A | Improvement Using Metco 1720A Overlay |
|---|---|---|---|
| Metco 1720A | 375 $HV_{300}$ | 1.67 | --- |
| Inconel 625 | 280 $HV_{300}$ | 1.38 | ≈ 25 % |
| Ultimet | 300 $HV_{300}$ | 1.00 | ≈ 67 % |

**Figure 10.** Comparison of hardness and abrasion resistance for non-marine protective overlays. Metco 1720A overlays exhibit hardness and abrasion resistance that is significantly higher traditional Inconel 625 or Ultimet overlays. Based on cladding trials, Metco 1720A can be expected to produce a minimum hardness of 350 $HV_{300}$. Note: Abrasion resistance is based on normalized volume loss where higher numbers in the graph are better.

- Proprietary nickel-based alloy developed using our Scoperta RAD
- Patent pending
- Manufactured in-house by Metco Joining & Cladding using gas atomization
- Spherical podwer particles of consistent chemical composition
- Similar overlay properties are produced using either conventional laser cladding or ultra high-speed laser cladding
- Overlays exhibit corrosion resistance similar to Inconel 625 and similar to Ultimet for hydraulic cylinder rod environments
- Higher hardness and abrasion resistance compared to Inconel 625 and Ultimet overlays

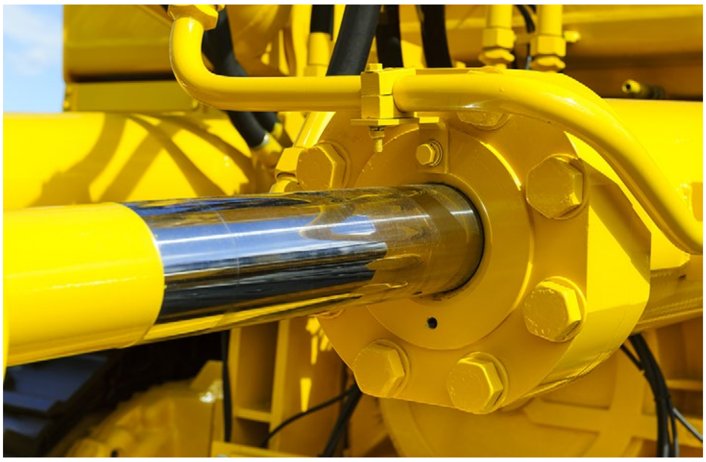


**Figure 11.** A finished hydraulic rod.

### 4.2 Corrosion Resistance

Corrosion testing, specifically ASTM B117, ASTM G59, ASTM G61 and ASTM G48, show overlays of Metco 1720x material series have similar performance to Ultimet.

| Overlay Alloy | ASTM B117 Salt Spray Test (1000 h) | ASTM G59/G61 (< 0.01 mpy) | | ASTM G48 Rm Temp, 40 °C Pitting Resistance |
|---|---|---|---|---|
| | | Tafel Extrapolation | Linear Polarization | |
| Metco 1720x | Pass | Pass | Pass | Pass |
| Inconel 625 | Pass | Pass | Pass | Pass |
| Ultimet | Pass | Pass | Pass | Pass |

**Table 4.** Corrosion testing comparing overlays of Metco 1720x, Inconel 625 and Ultimet

After 1000 hours exposure to salt spray in the ASTM B117 test, the Metco 1720x overlay did not show any signs of rust or damage. This is similar to the performance of Inconel 625 and Ultimet overlays in this test.

ASTM G59 and ASTM G61 testing showed that the corrosion rate of the Metco 1720x overlays are below 0.1 mpy which is in line with the results of the incumbent materials.

The last test performed was the ASTM G48-A to determine the pitting resistance of these overlays at room temperature and 40 °C. At both temperatures, there was no pitting seen on any of the samples indicating that the Metco 1720x overlays have similar pitting resistance to Inconel 625 and Ultimet in this corrosion environment (Table 4).

### 4.3 Finishing of Metco 1720x Series Overlays

Metco 1720B, clad via EHLA, finishes to customer standards when using grinding processes.

Operators noted they did not have issues finishing the rods using processes equivalent to finishing standard nickel-based overlays.

Metco 1720x series overlays have been successfully clad crack-free in all laser cladding trials without the need for preheating.

### 4.4 Summary: Metco 1720x Series

In conclusion, Metco 1720x overlays exhibit a wide application window for producing a crack-free coating that has comparable corrosion resistance and better abrasion resistance than Inconel 625 and Ultimet, making it well-suited for hydraulic rod applications in marine environments.

## 5 Relevant Applications

The Metco 1020x and Metco 1720x series of materials are suitable for all types of hydraulic cylinder rod applications to replace hard chromium plating and other conventional protective overlays. Additional applications include:

- Dimensional Restoration
- Hydroelectric valves
- Exhaust fans
- Cylinder liners
- Pump plungers
- Bearing surfaces
- Pump seals
- Pump liners

## Customer Benefits

### Effective

- Improves on current protective overlays such as 400-series stainless steels for non-marine environments and nickel-based or cobalt-based overlays (Inconel 625 and Ultimet respectively) for marine environments
- Offers similar or better corrosion resistance
- Offers significantly better abrasion resistance
- Finish grind to the high surface finishes needed for hydraulic rod applications

### Economical

- No additional processing steps required to apply Metco 1020x series or Metco 1720x series versus other iron- or nickel-based overlays
- Elimination of preheat lowers applications costs
- Improved abrasion resistance extends the service life of cylinder rods and lowers operating costs

### Efficient

- Product versions available with particle size distributions optimized for standard application processes (e.g., standard laser cladding, EHLA and PTA
- Produces crack-free overlays, enhancing corrosion resistance
- Can be applied in multiple layers
- Materials allow a wide application window that provides highly reproducible overlays

### Environmental

- Eliminates hard-chromium plating and Cr(VI)
- Cobalt-free compositions



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