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Solutions Flash

New Wear-Resistant Materials for Mud Motor Rotors for Oil and Gas Drilling Offer Excellent Corrosion Resistance and Ductility

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Today's Situation

As we are all aware, the days of easily accessible oil reservoirs are long behind us. Today, drill strings go deeper and deeper and directional drilling is often the best way to reach these deposits.

Essential to the operation of these long drill strings and directional drilling is the mud motor to provide additional power to the drill bit. Of course, critical to the mud motor is the rotor.

Traditionally, the industry uses hard chromium plating or tungsten carbide coatings (typically WC-10Co-4Cr) to protect the rotor from wear. While these coatings offer excellent wear protection, they are problematic in other ways.

To achieve the thickness required for hard chromium plate, these components can require very long plating times. In addition, the size of these parts requires a large plating bath, which are in relatively short supply. Further, as a result of regulations to control carcinogenic Cr^{6+}, hard chromium plating continues to rise in cost and become more difficult logistically.

Conversely, while rotors coated with tungsten carbide coatings can be processed relatively quickly, the process times to coat and grind the rotors are still not optimal.

Of even greater concern is the fact that neither hard chromium plating nor tungsten carbide coatings are particularly corrosion resistant in acidic or alkaline environments with chloride ions. Tungsten carbide coatings are relatively brittle and as the rotors are prone to flexing both in handling and in service, the coating has a tendency to crack. Hard chromium

plating exhibits naturally-occcuring microcracks. These cracks lead to pathways for the corrosive media to reach the rotor.

Exacerbating the issue is the fact that spallation of the coating and corrosion pits on the rotor can lead to sharp edges, which can ruin the elastomer stator lining.

These issues result in reduced operational efficiency of the mud motor. In some cases, the damage can be so severe that the mud motor seizes resulting in a costly and time-consuming drill string trip.

The Oerlikon Metco Solution

Oerlikon Metco has developed wear-resistant carbide materials that help to alleviate the shortcomings of hard chromium plating and traditional tungsten carbide coatings.

These carbide materials employ a unique nickel-copper (NiCu) matrix that is both more corrosion-resistant and far less prone to 'under corrosion' than traditional rotor coatings. The NiCu matrix offers improved ductility that significantly reduces the potential for cracking of the coating during handling and operation of the rotor. Coatings of these materials perform very well with drill muds that are acidic oralkaline chloride-containing environments.

The improved ductility also results in very good impact resistance. Wear properties of these coatings are very suitable to the operating environments of mud motor rotors. The improved corrosion resistance also reduces the potential of damage to the elastomer stator.

Like traditional tungsten carbide coatings, coatings of these materials can be ground to very good finishes. They are applied using HVOF (high velocity oxygen fuel spray) which results in dense, low porosity coating structures. Coating of the rotors is relatively fast, and these materials are more cost effective than traditional WC-10Co-4Cr. In addition, the improved corrosion resistance means a reduction in manual spot welding of pits to repair the rotor.

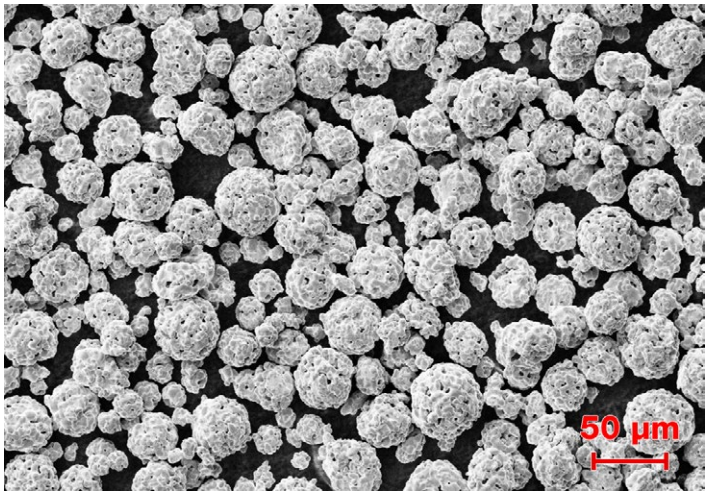
Finally, these coatings can be spot repaired with very good results. Such repairs are not possible with either hard chromium plating or traditional tungsten carbide coatings.

Solution Description and Validation

1. Introduction

Metco 5280A and Metco 5580A are spheroidal, agglomerated and sintered powders for thermal spraying containing 70 wt. % chromium carbide or a combination of tungsten carbide and chromium carbide as the hard phase constituent and a 30 wt. % nickel-copper alloy as the binder material. Coatings of these materials provide sufficient wear resistance for this application while providing additional processing and service characteristics that traditional carbide coatings cannot.

Metco 5280A and Metco 5580A are designed to be applied using the liquid-fuel HVOF process with better cost efficiency than traditional WC-10Co-4Cr. When properly applied, coatings exhibit low porosity (< 1 %) and exhibit excellent ductility and corrosion resistance compared to coatings of either WC-10Co-4Cr or hard chromium plating.



SEM of Metco 5280A show typical morphology of these powders

Product	Nominal Composition	Nominal Particle Size Distribution (µm)	Manufacturing Method
Metco 5280A	70Cr_3C_2 21Ni 9Cu	-45 +20	Agglomerated and Sintered
Metco 5580A	70(WC/Cr_3C2) 21Ni 9Cu	-45 +15	Agglomerated and Sintered

2. Corrosion Issues with Traditional Carbide Coatings and Hard Chromium Plating

The usual failure mechanism of rotors coated with traditional carbide coatings or hard chromium plating is delamination of the coating due to under corrosion, which leads to severe local pitting corrosion of the rotor.

For the customer, failure means:

- Lost drilling productivity and a lengthy drill string trip
- Removing the rotor from service as it will require stripping and recoating
- Each time the rotor is stripped and recoated, there is some dimensional loss thereby reducing rotor service life
- The corrosion damage on the rotor may result in damage to the elastomer stator lining, resulting in further costly repairs

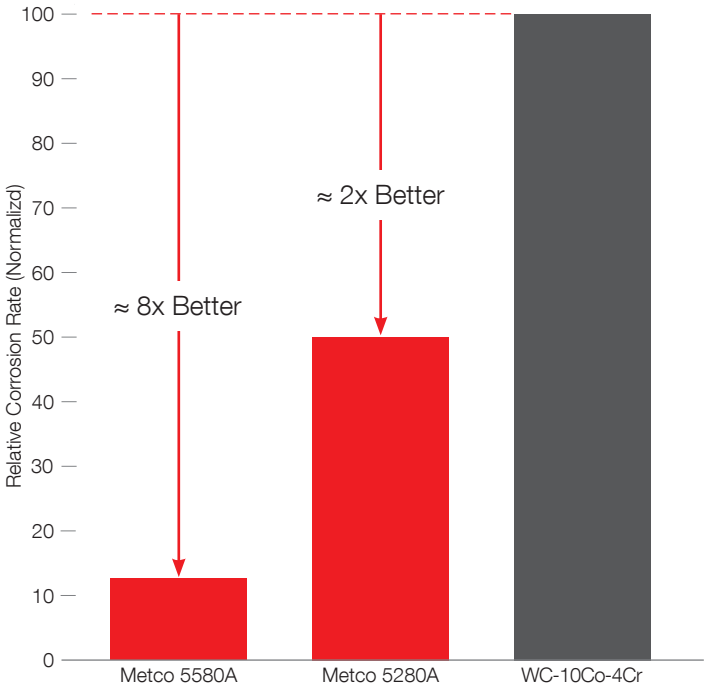
Some issues of traditional coating application:

- Any pitting damage must first be repaired by cleaning, spot welding and grinding each individual pit
- Rotors flex easily and must be carefully handled to avoid cracking of the coating
- Hard chromium facilities are decreasing resulting in rising costs for hard chromium plating
- Spot repairs of the coating, if needed, are difficult or just not possible

Pitted rotors

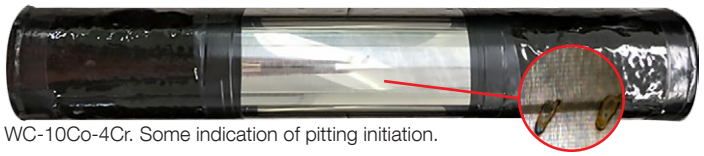
3. Corrosion Resistance of Metco 5280A and Metco 5580A

3.1 Corrosion test in high chloride drill brine (28 % $CaCl_2$, pH9 electrolyte)



The nickel-copper matrix provides highly improved corrosion resistance that results in longer service life, less wear on the housing and less pitting damage.

3.2 Corrosion immersion test results after 1000 h in aerated salt water 3.5% NaCl at room temperature



WC-10Co-4Cr. Some indication of pitting initiation.

Metco 5280A. No pitting.

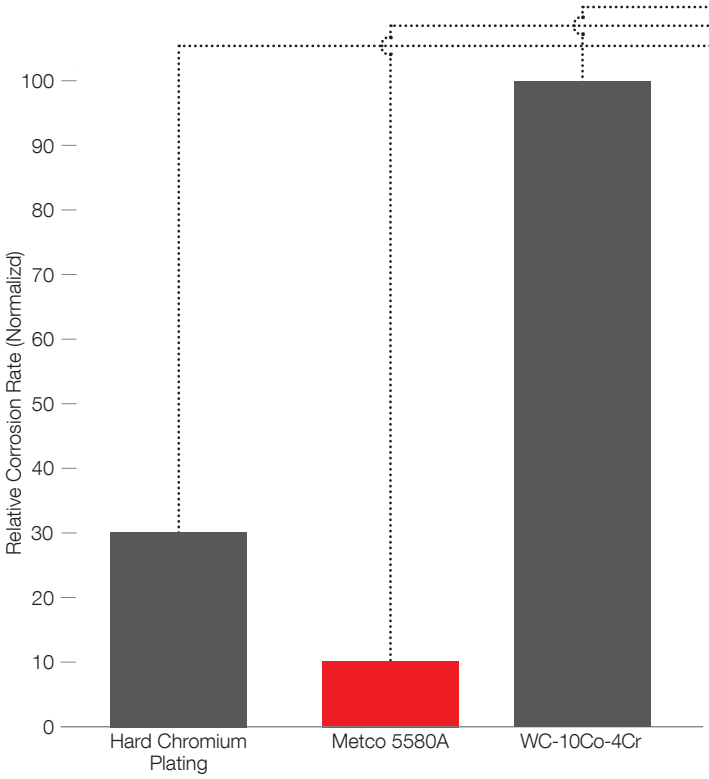
Metco 5580A. No pitting.

While all three coatings did well in this test, the samples coated with Metco 5280A and Metco 5580A did not exhibit any corrosion after 1000 hours.

3.3 O&G OEM High Temperature Sour Service Test

17-4PH stainless steel coupons coated with Metco 5280A and Metco 5580A were exposed to acidified NaCl brine (25 % NaCl; pH 4) at 150 °C (316 °F) for 168 hours. The coupons showed no indications of corrosion.

3.4 Cyclic polarization and Tafel experiment for an acidic environment (28 % $CaCl_2$, pH2 adjusted with HCl)



Hard Chromium Plating | Metco 5580A | WC-10Co-4Cr

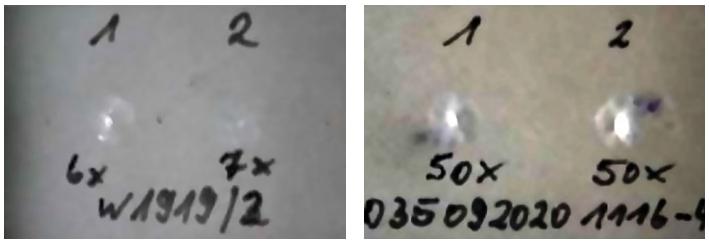
As can be seen from the graph to the left, WC-10Co-4Cr does not hold up well in acidic environments. While hard chromium plating was better than WC-10Co-4Cr, Metco 5580A performed significantly better than either. Metco 5280A was not testes in an acidic environment, but it can be seen that both Metco 5280A and Metco 5580A performed very well in an alkaline test.

Shown above are coupons from the acidic test. Note that the hard chromium plate and WC-10Co-4Cr coating coupons exhibit rust from the substrate, but the Metco 5580A coupon does not.

4. Impact Resistance

Coatings of Metco 5280A and Metco 5580A can absorb at least 7-times more impact energy than WC-10Co-4Cr, demonstrating their significantly higher resistance to damage.

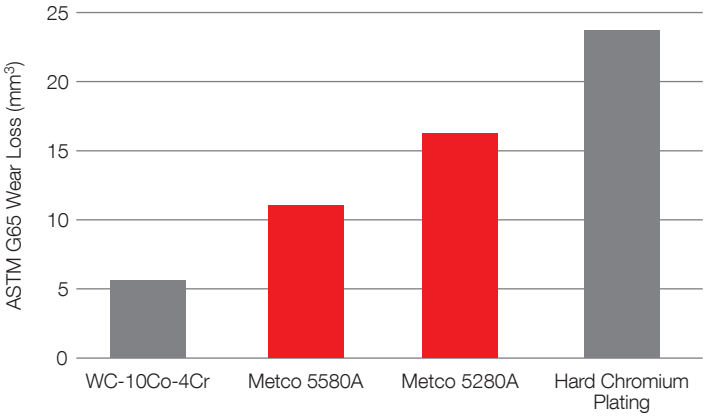
Coating	Number of Drops	Total Energy [J]
WC-10Co-4Cr	6 / 7	25 to 29
Metco 5280A	50 / 50+	207+
Metco 5580A	46 / 50+	190 to 207+



Left: The WC-10Co-4Cr coating delaminates after a low number of drops.
Right: The coating of Metco 5280A plastically deforms at approximately 8x higher energy and approximately 8x the number of drops.

5. Wear Resistance

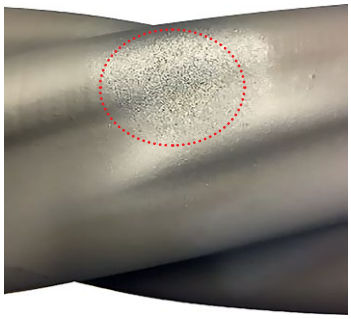
As corrosion rather than wear is often the limiting factor in mud motor rotor applications, the wear resistance offered by coatings of Metco 5280A and Metco 5580A are fit for this purpose with wear resistance better than hard chromium plating but not quite as good as traditional tungsten carbide coatings.



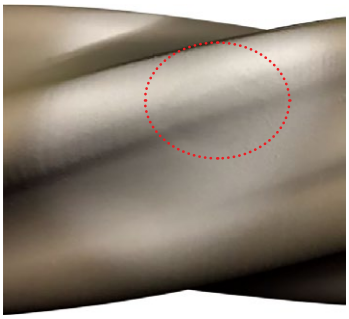
6. Spot Repairs

The unique compositions of Metco 5280A and Metco 5580A as well as the ductility and bond strength of these coatings allow them to be spot repaired with excellent results. Such repairs are not possible with either hard chromium plating nor traditional tungsten carbide coatings.

This repair technology can save substantial costs and time compared to completely stripping and recoating the rotor.

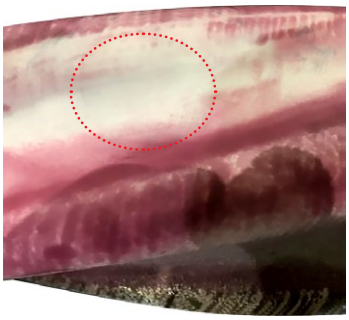


Local grit blasting of the defect area down to base metal does not flake or have rough edges.



The area to be repaired is HVOF sprayed and already blends well.

After local grinding of the patch the repaired area grinds to a smooth finish and blends perfectly.



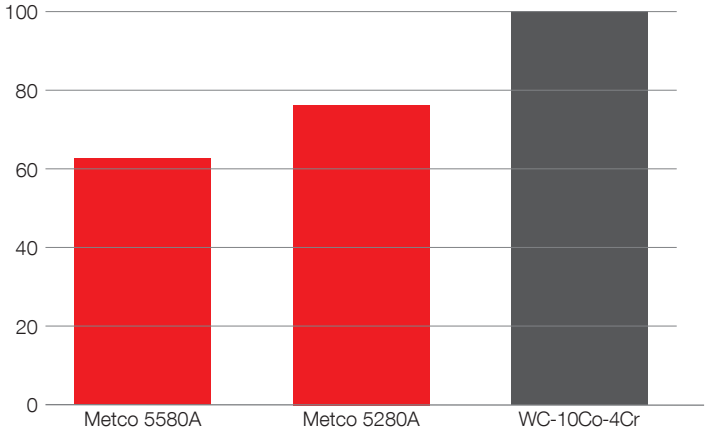
Dye penetrant testing of the patched area does not indicate any cracking or undesired porosity.

7. Cost Savings

Coatings of Metco 5280A and Metco 5580A offer cost savings in both material and processing costs. In addition, the improved ductility and impact resistance of these coatings also save costs as a result of reduced cracking of the coatings during handling and in service.

7.1 Relative consumption

Powder Consumption per Unit Area [% Normalized]

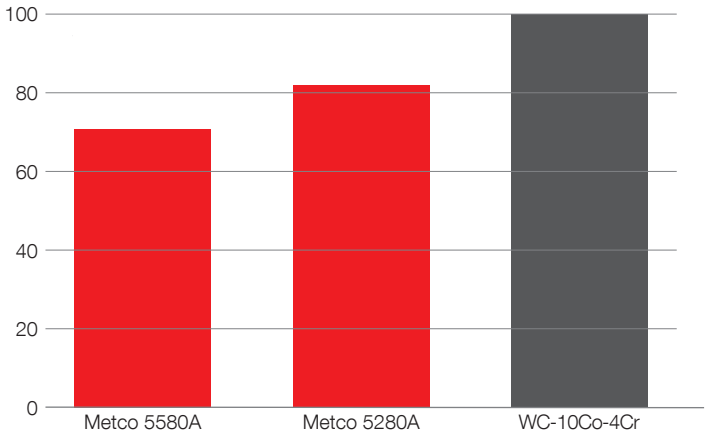


Compared to WC-10Co-4Cr, some customers have reported that the material needed (weight per unit area coated) to achieve the same coating thickness is significantly lower for both Metco 5580A and Metco 5280A.

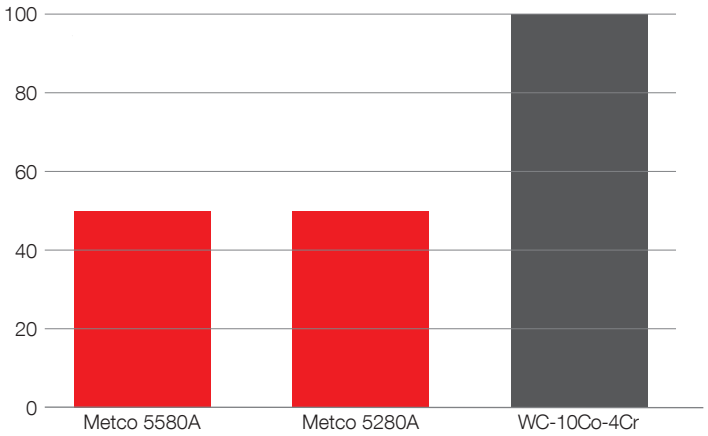
This means that customers can choose between applying thicker coatings for enhanced wear resistance or save materials costs and time by applying coatings of the same thickness as WC-10Co-4Cr.

7.2 Relative processing costs

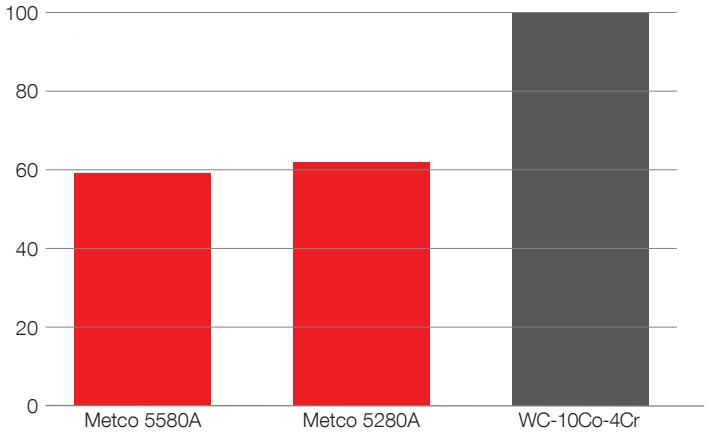
Time to Thermal Spray Coating [% Normalized]



Grinding Time [% Normalized]



Total Processing Time [% Normalized]



Metco 5280A and Metco 5580A can be applied using HVOF-LF up to 30 % faster than traditional WC-10Co-4Cr. Customers have reported that they can grind these coatings in half the time it takes to grind WC-10Co-4Cr.

Overall, this results in a total processing time savings of as much as 40 %!

Please note that there are, of course, also additional cost savings in processing, such as labor, process gases, grinding media, etc., that are not accounted for in these calculations. And when compared to the processing time for hard chromium plating — which can require days in the plating bath to achieve the required plating thickness — the HVOF-LF thermal spray option is considerably faster, requiring only hours to complete.

7.3 Pitting repair

The improved corrosion resistance achieved with coatings of Metco 5280A and Metco 5580A results in significantly fewer pits in the rotor.

The time required for cleaning, manually welding and blending in the weld repairs can be quite time consuming.

Customers have reported that the average time to repair pits in a hard chromium plated rotor to be as much as 48 hours per rotor. With the corrosion protection provided by Metco 5280A and Metco 5580A coatings, their average time to repair pits for a single rotor has dropped substantially.

Customer Benefits

Effective

- Provides wear resistance appropriate for mud motor applications
- Corrosion-resistant coatings protect mud motors far better against pitting corrosion from acidic, alkaline or chloride ion drilling muds
- Reduce pits by as much as 90 % compared to hard chromium plating
- Improved ductility and impact resistance results in a 7x reduction in cracking of the coating from handling of the rotors and in service reducing pathways for corrodants to reach the rotor
- Dimensional restoration possible with no additional build-up layer required — a simple one step coating process
- Spot repairs with excellent results are possible that are not possible with WC-10Co-4Cr or hard chromium plating

Environmental

- Reduce dependence on hard chromium plating and carcinogenic Cr^{6+}
- Reduce waste as a function of reduced requirements for stripping and recoating as a result of coating damage

Economical

- Reduction in coating processing time of up to 40 % saves on labor, process gases and more
- Reduction in grinding time of up to 50 % saves on labor and grinding media
- Overall reduction in applied material costs compared to WC-10Co-4Cr
- Drastic reduction in time and cost to repair pits in rotors

Efficient

- Reduced corrosion with very good wear protection can reduce drill string trips
- Easily applied using liquid-fuel HVOF thermal spray
- Total processing time for a rotor cut to hours compared to days for build up of hard chromium plating
- Low stress in the coatings means that thicker coatings are possible for additional wear protection
- Better corrosion resistance and ductility results in longer rotor service life

Information is subject to change without prior notice.

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