EXPLORING LOW-TEMPERATURE ALTERNATIVES TO ELECTROLYTIC HARD CHROME COATINGS

Kinetic metallization offers certain advantages over hard chrome and thermal spray coatings, especially when elevated process temperatures would degrade the coating or part.

Ralph Tapphorn and Howard Gabel, Inovati, Santa Barbara, Calif.

Electrolytic hard chrome (EHC) coatings are used to enhance wear and corrosion resistance in a wide variety of markets and applications, including hydraulics, tooling, and aerospace components. However, the EHC process presents serious health and safety concerns, generating a hazardous waste stream of known carcinogens. More stringent regulations and penalties issued by the U.S. Occupational Safety and Health Administration (OSHA) for unsafe handling of the waste products add to the urgency of developing alternatives to EHC.

Many users turned to WC-Co coatings applied using the high-velocity oxygen fuel (HVOF) thermal spray process, which has its own drawbacks and limitations. For example, HVOF operates at combustion flame temperatures over 5000°F (2760°C)[1] and requires a specially designed sound-deadening booth to protect the hearing of operators[2] and others nearby. These booths often have a large footprint and require additional high-capacity dust collection systems to operate. Further, the high operating temperature of HVOF can cause decarburization and oxidation of WC-Co feedstock, degrading coating quality and performance[1,3]. High jet temperatures also limit the types of parts and materials that can be coated using HVOF. Because HVOF can melt small parts and degrade the temper of larger parts, measures typically must be taken to keep parts sufficiently cool during processing, including restricted preheating, in-process cooling, interpass spray pauses, and controlled post-deposition cooling rates[3,4].

ADVANTAGES OF KINETIC METALLIZATION

Kinetic metallization* (KM) offers a number of advantages over HVOF including low process temperature, efficient powder use, and inherent process control and documentation. The KM process operates at a nominal gas pressure of 70 psig (480 kPa), using a patented friction-compensated sonic nozzle to accelerate specially formulated feedstock particles to velocities of over 1000 m/s[5]. As particles impact the substrate, they deform and expose a new oxide-free surface, which enables the formation of strong cohesive and adhesive bonds. A patented powder fluidizing unit (powder feeder) and friction-compensated sonic nozzle from Inovati enable KM equipment to reliably deposit a wide range of materials including WC-Co coatings (Fig. 1)[6]. Process characteristics for KM and HVOF WC-Co coatings and EHC are shown in Table 1 and a detailed comparison of KM and HVOF WC-Co coatings is provided in the literature[7].

Fig. 1 — Kinetic metallization production coating system for application of WC-Co and other hard phase wear and corrosion-resistant coatings.

The advantages of KM versus other techniques include the following considerations:

Low process temperature. KM is a low heat input process. KM coatings are deposited at temperatures of only a few hundred degrees Fahrenheit, precluding melting of feedstock and substrate. A low KM deposition temperature prevents decarburization and oxidation of the feedstock, resulting in higher quality WC-based coatings. The process works particularly well for small parts and can be deposited on internal diameters as small as 50 mm.

Low heat input enables providing the required wear resistance in components that cannot withstand the high temperatures of HVOF and other thermal spray processes. In addition, independent testing performed by U.S. Navy, Naval Air Systems Command (NAVAIR) verified that coatings using KM provide a good low-temperature alternative to hard chrome plate[8]. For example, NAVAIR's Fleet Readiness Center Southwest conducted special accelerated wear testing to compare material loss from uncoated, hard chrome plated, and KM WC-Co coated AMS 6265 alloy gearshafts. In the test, the shaft was rotated at a fixed rpm with the shaft seal installed in a NAVAIR F/A-18E/F Super Hornet jet fighter airframe mounted accessory drive (AMAD) gearbox contaminated with a grit slurry. After roughly 20 hours of testing, the uncoated and plated shafts

TABLE 1 - COMPARISON OF PROCESS CHARACTERISTICS

Characteristic	Kinetic metallization WC-Co	High velocity oxygen fuel (HVOF) WC-Co	Electrolytic hard chrome (EHC)
Byproducts	Inert powder	Heat, oxides, overspray	Toxins, carcinogens
Target efficiency	Same as DE*	Much lower than DE	N/A
Wear resistance	Better than EHC	Better than EHC	Good
Noise, dBA	74	140	N/A
Deposition temperature, °C	<200	>1500	<100
As-deposited surface roughness (Ra), µin.	63	Rough	Edge buildup
Time to produce coating	Minutes	Minutes	Up to 1 day
Mobility	Mobile system offered	Varies	No
Unit footprint	6 × 6 ft	>10 × >15 ft	Varies by part size
Substrate degradation	No	Likely	Varies
Worker protection	Some respiratory, minor skin protection	Significant respiratory and auditory, minor skin protection	Significant respiratory, skin protection
Hardness (HV_{300g})	800-1500	800-1200	700-1000

*DE is deposition efficiency, the percentage of feedstock that deposits on a standard flat surface.

suffered from deep grooving. The KM-coated shaft suffered no grooving, including after an additional 40 hours of testing. This part could not be coated using HVOF thermal spray because the high jet temperatures would degrade the substrate and its heat-treated properties.

Performance of the component repaired using KM is superior to that of the uncoated OEM component (Fig. 2) and the chrome-plated component, and the KM-coated part is currently in service on F-18s. This coating solution is currently being tested on all rotating and stator components of the AMAD gearbox to qualify the repair method for general use on worn aircraft components such as those shown in Fig. 3.

Efficient use of powder. The width of the KM spray jet impinging on the part being coated is about 10% that of HVOF, which enhances target efficiency (TE), or deposition efficiency (DE), the percentage of feedstock that deposits on an actual production part. Further, the low-temperature process enables the spray jet to remain on the part throughout the coating period, eliminating the need for powder-wasting pauses to limit part heating.

Simplicity and safety. KM does not require extra hardware or safety equipment. The process uses only inert gas and benign feedstock powders. There are no chemical reactions, so there are no toxic byproducts. Release of particulates is easily prevented by using a single-cartridge dust collector equipped

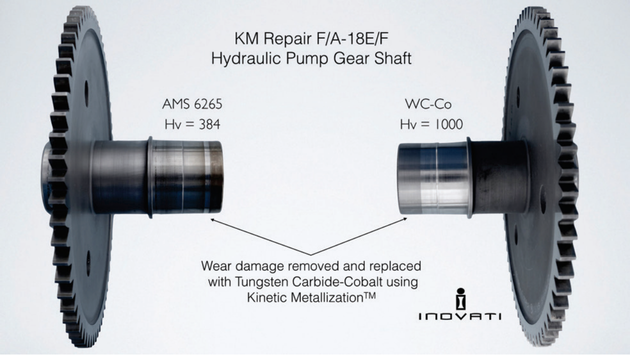

Fig. 2 — Wear damage on hydraulic pump gearshaft (left); repaired shaft using KM WC-Co coating (right).

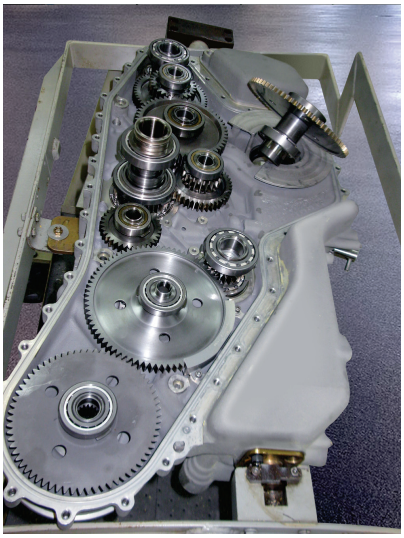

Fig. 3 — NAVAIR F/A-18E/F Super Hornet jet fighter AMAD gearbox showing gearshafts repaired using the KM production coating system. Courtesy of NAVAIR Fleet Readiness Center Southwest, San Diego.

with a HEPA final filter. Additionally, the sound levels associated with KM are below occupational hazard levels, so the system does not require a soundproof booth to protect the operator. Sound levels are low enough that an operator positioned at the control cabinet can run the system without using personal hearing protection for an indefinite amount of time while complying with OSHA noise standards (OSHA 1910.95)[9].

Built-in process documentation. KM equipment provides precise process control and complete operating records. Systems log all process data during operation and generate objective quality evidence reports at the end of every coating session. Reports are traceable records of system operation and performance. These records can be checked later to verify correct coating application and proper system performance, which helps maintain consistency between runs and validate and certify the services performed.

OTHER KM APPLICATIONS

Kinetic metallization can be used to apply a wide variety of coating compositions on many component types and geometries including:

- *Turbopumps.* KM WC-Co (HF-10-10) coatings are lapped to a flatness of <840 nm.
- *Upstream oil exploration equipment.* KM HF-20-30 is a corrosion resistant variation of KM HF-10-10 that passes 1000 hours of ASTM B117 salt fog testing while still exhibiting a microindentation hardness of 900 HV_{300g}.
- *Aerospace components.* KM Al-Trans* 10-20-50 is a proven environmentally friendly, iron vapor deposition (IVD) and AlClad repair, as well as a replacement for brush cadmium, which offers superior corrosion protection and can be used for additive manufacturing and dimensional restoration.
- *Automotive engine components.* KM WC-Co (HF-10-10) is routinely applied to repair vintage racing crankshafts.

*Kinetic Metallization is a trademark, and Al-Trans is a registered trademark, of Inovati. **~iTSSe**

For more information: Ralph Tapphorn is vice president of technology, Inovati, 1501 Cook Place, Santa Barbara, CA 93117, 805.571.6200, info@inovati.com, www.inovati.com.

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