Kinetic Metallization Compared with HVOF

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F/A-22 Raptor in early test fight (photo USAF). F/A-22 candidate KM WC-Co coating requirements include landing gear actuators and cylinders, landing gear door actuators, flight surface actuators, flap and slat racks, thrust reversers, lugs, and axles.

Kinetic metallization (KM) is a solid-state process in which metallic powders are sprayed through a specially designed, two phase, sonic deposition nozzle that accelerates metal particles entrained in an inert carrier gas. Once accelerated to high speed, the particles are directed onto a substrate, onto a mandrel, or into a mold. Subsequent high-speed collision of the metal particles causes very large strain (approximately 80% in the direction normal to impact) in the particles. This deformation results in a huge increase in particle surface area (approximately 400%), producing a new surface that is oxide free. When these active surfaces come into contact, pure metallurgical bonds are formed. Metallurgical bonding is achieved exclusively through the solid-state reaction, with no bulk melting.

Kinetic metallization is now accepted as a viable process for application of such diverse coatings as Inovati's AlTrans (aluminum-transition metal) on steel telecommunications equipment racks, WC-Co on aerospace actuators, and Cu-Cr and MCrAlY on rocket engine thrust chambers.

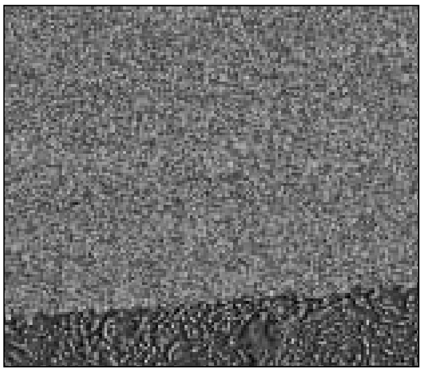
This article begins with a comparison of the steps involved in HVOF and kinetic metallization, then provides comparison of the costs of the two processes for WC-17Co wear-resistant coatings as applied to aerospace actuators.

Process comparison

High-velocity oxy-fuel (HVOF) is a classic thermal spray process in that it relies on the combustion of a fuel and an oxidizer to generate combustion products that form an accelerant gas. Energy released by this combustion process produces high pressure in the accelerant gas and heats the gas to a temperature above the melting point of the feedstock. This provides sufficient energy to drive the accelerant gas to supersonic velocity.

The resultant high particle temperature and high particle velocity produce coatings with less porosity than possible in most other thermal spray processes. However, HVOF introduces a composite microstructure consisting of re-solidified particles, solid particles, and oxides. Moreover, it requires surface pretreatment and, in most cases, thermal management such as preheating, in-process cooling, and post-process cool-down. Additionally, the hot particles are subject to chemical reactions such as decarburization during deposition.

By contrast, in the KM process the energy content of compressed gas accelerates particles to sonic velocity. Separately, a small (<2500 watt) resistance heater provides the heat necessary to thermally soften the particles, but never to melt them. The nozzle design limits accelerant gas velocity to below the velocity of sound, but maximizes gas density and thus dynamic pressure through the entire length of the nozzle. KM coatings are characterized by low or no porosity and pure metallic, very fine-grained microstructure. No surface pretreatment or thermal management is required.



This is a scanning electron microscope image of a WC-17 Co coating applied by kinetic metallization on 4340 steel.

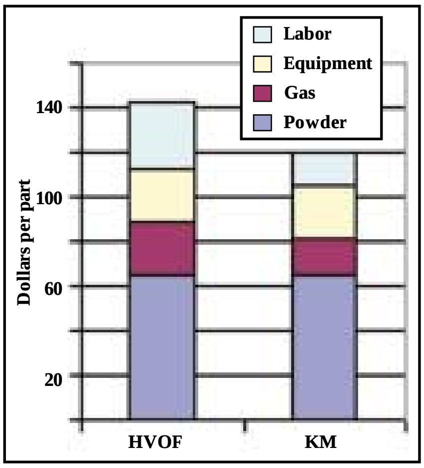
Table 1 compares HVOF and KM in terms of accelerant energy source, particle heat source, characteristic gas velocity, and microstructure. Table 2 illustrates single-step KM in contrast to four-step HVOF.

Table 1 — Comparison of energy and microstructure in HVOF and kinetic metallization

Characteristic	HVOF	KM
Accelerant energy	Combustion	Expansion
Particle heat	Combustion	Resistive
Gas velocity	Supersonic	Sonic
Microstructure	Composite	Metallic

Table 2— Process flow comparison

Process	Processing steps			
HVOF	Grit blast	Preheat	Coat / cool	Cool down
KM	—	—	Coat	—



Part cost summary, HVOF compared with kinetic metallization.

Table 3 — Cost summary, HVOF compared with KM

Annual cost summary	HVOF	KM
Powder	$111,720.00	$98,000.00
Gas	35,524.51	24,180.00
Equipment	35,714.29	35,714.29
Labor	44,625.00	22,440.00
Total Cost	227,583.80	180,334.29

Table 4 —Cost detail of HVOF and kinetic metallization

Cost detail	HVOF	KM
Equipment and installation, $	250,000.00	250,000.00
WC-Co powder, $/pound	22.80	20.00
Gas cost, $/100 SCF	—	—
Recycled helium (including amortized equipment cost)	—	5.50
Oxygen	2.20	—
Hydrogen	4.20	—
Nitrogen	2.90	—
Preparation/spray labor, hours/part	1.75	0.88

Technical cost analysis

Several assumptions are common to both processes for the coating of a hypothetical aerospace actuator fabricated from 4340 steel. The dimensions of the section of the actuator are assumed to be four inches in diameter, 36 inches in length. The applied coating is 0.008 in. thick. It is further assumed that 1500 parts per year will be coated. The hourly (unsupervised, unloaded) labor rate is $17 per hour. Equivalent coatings are deposited at 60% deposition efficiency. Capital equipment cost is amortized over a seven-year life. Real estate costs and utility costs are not considered.

For HVOF, capital costs include HVOF deposition equipment, powder feeder, soundproof room, dust collector, air compressor, fuel and oxygen supply system, grit blast preparation system, and equipment installation costs. Masking consumables and labor are not included.

For KM, capital costs include deposition equipment, which includes a helium supply system, powder fluidizing unit, thermal conditioning unit, sonic deposition nozzle, a dust collector, and installation costs. A helium recycle system is not a capitalized item; rather, the cost associated with this equipment is included in the gas cost shown in Table 3.

KM is a one-step process consisting only of applying the coating, whereas HVOF requires several additional steps. The throughput and cost penalties associated with grit blasting, preheating, in-process cooling, and post-process cooling for HVOF are included in this analysis. They account for the higher labor costs relative to KM, as shown in Table 4.

Lower-cost choice

KM is a lower cost alternative to HVOF for the deposit of high-quality WC-Co on aerospace actuators. Similar savings are expected with other cemented carbide formulations. Feedstock for KM differs from that for HVOF. The KM feedstock is a proprietary formulation that is lower in cost, and yet results in coatings with finer, denser, and more uniform microstructures. This lower cost feedstock contributes to the cost advantage presented here. ■

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KM equipment will be on display at the ASM International Aeromat Exhibition in Seattle, June 20-23, 2004.

KM is not cold spray

Kinetic metallization is sometimes confused with cold spray. However, Kinetic Metallization is a substantially different process. All of the Cold Spray variants rely on the injection of metal particles into a supersonic stream of accelerant gas, a very inefficient way to accelerate heavy particles with a light gas. KM features a friction-compensated sonic nozzle to accelerate particles. Thus KM accelerates particles to higher velocity than the cold spray variants, but does so with 10% of the gas flow, and thus at 10% of the accelerant gas cost (Table 5).

This cost advantage is magnified when the gas is recycled, because the lower-pressure, lower-flow-rate gas can be recycled with equipment costing only 5% of that required for high-pressure, high-flow cold spray systems. Note that recycled gas cost in Table 6 is significantly lower than in the hypothetical example covered in the text of this article. The data this table assume a 100% duty cycle (fully dedicated equipment) and that in the text is based on 1500 parts per year.

Table 5 — Cost comparison with cold spray

Nozzle	Supersonic	KM sonic
Accelerant	He	He
Pressure, psi	500	50
Flow, SCFM	75	7.5
Cost, $/SCF	0.10	0.10
Cost, $/min	7.50	0.75
Cost, $/lb	150	15

Table 6 — Cost advantage with recycled gas

Nozzle	Supersonic	Supersonic recycle	KM sonic recycle
Accelerant	N2	He	He
Pressure, psi	500	500	50
Flow, SCFM	26.5	75	7.5
Cost, $/SCF	0.04	0.03	0.02
Cost, $/min	1.06	2.25	0.16
Cost, $/lb	9	32	3