Preliminary Evaluation of KEM for Fabrication

T. S. Chow and S. W. Kang
Lawrence Livermore National Laboratory
P. O. Box 808, Livermore, CA 94550
U. S. A.

Ralph Tapphorn and Howard Gabel
Innovative Technology Inc.
Las Cruces, NM 88004
U. S. A.

(The 12th General Meeting of JOWOG 31, Livermore, CA USA)

Introduction

Kinetic Energy Metallization (KEM) is an emerging deposition process that uses metal powder as feed stock without external heating (Reference 1[1]). Metal powder mixed with gas is accelerated through a supersonic nozzle directed toward the substrate to be coated. Collisions occur between the powder and the substrate, causing fresh active metal to be exposed. When these active surfaces contact one another, they agglomerate and form true metallic bonds.

KEM differs from other metal coating processes because it is essentially a solid state process. Other processes are gas, liquid, or solution based. Thermal spray coating is the most closely related to KEM. These processes rely on the input of large quantities of thermal energy to rapidly expand the carrier gas and thereby propel molten particles to the substrate.

KEM's high rate of deposition makes it a good stand-alone process for forming of net shape thin wall parts. It is also a unique technique for refurbishment or repair of recycled parts, or the creation of attachment features on blanks (made by other processes) that are susceptible to high temperature distortion and/or over-aging.

The deposition materials can be metal on metal (e.g., Al, Cu, Ni, U, Zn, W) or metal on plastics. The potential applications include both defense and civilian areas. Uranium-alloy case fabrication and refurbishment are important weapons applications. Micro-electronic circuitry, optics casing for aerospace, turbine blade repair, and artificial-limb joint coating are also potential KEM applications.

The KEM process is a proprietary technology, developed by Innovative Technology Inc., (ITI), the experiments reported here were performed at ITI's, Las Cruces, NM laboratory. ITI first observed the KEM phenomena in a supersonic particle ignition study, and has since demonstrated its feasibility as a coating process. The current work is a preliminary, ongoing evaluation of the process.

The objectives of this study are to demonstrate process feasibility by generating experimental data as a function of operational parameters and to establish better understanding of the particle-to-substrate bonding mechanism using computer modeling.

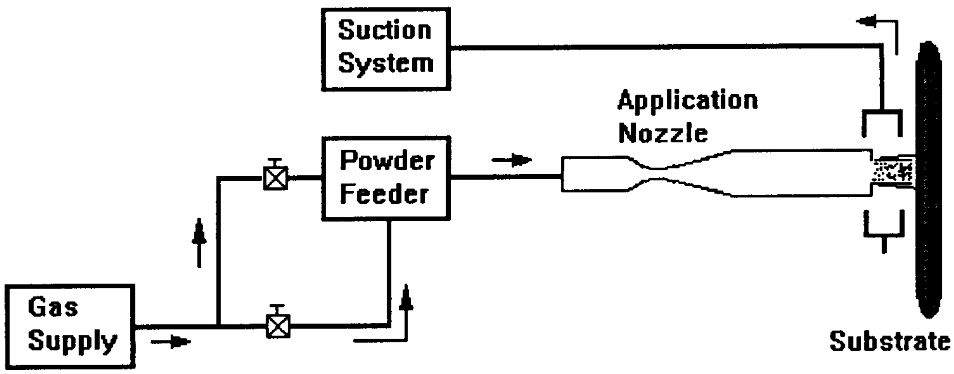
Experiments

The experimental setup is shown schematically in Figure 1, including a ceramic nozzle with a 1.6 mm diameter throat.

---

1 Ref. 1: "Surface modification by High Speed Macroscopic Particle Impact", H. Gabel and R. M. Tapphorn, Innovative Technology, Inc., Surface Modification Technologies IX, The Minerals, Metals & Materials Society, 1996

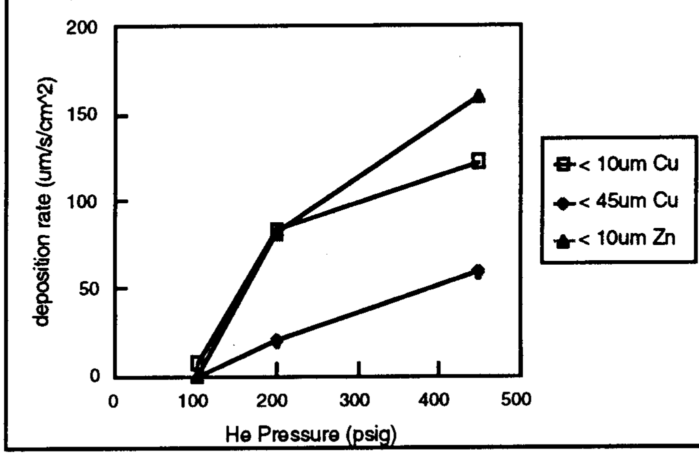
Figure 1 Schematic Representation of KEM System



System Performance -- Two types of samples were attempted: thin coating and thick (bulk) deposition samples. The actual coating thickness (build up) on the samples ranged from a few tens of microns to 2.5 mm. Thickness depended on dwell time, powder size and inlet pressure. Thicker coating were deposited at longer dwell times, smaller powder sizes, and higher inlet pressures. The deposition rates are representative of the current KEM laboratory configuration, including current powder feeder and nozzle designs.

Figure 2 is a plot of the deposition rate as a function of gas pressure. Comparison of deposition rates between different powders, e.g. Cu and Zn, can be difficult due to the effects of the powder feeder on the powder flow. The numbers, however, do show that a) the deposition rates increase with increasing gas pressure and decreasing powder size and b) the deposition rates can be high enough for practical applications.

Figure 2 Deposition Rate as a Function of He Pressure



The following is a summary of Rockwell Hardness (RH) measured for Cu powder applied to Al substrates and Zn powder applied to Al substrates. (Note that the RH measured for a 1.6 mm thick sheet of soft copper was 76 +/- 1.)

	He Pressure	RH
Cu: <10 (m	100	77 +/- 3
	200	85 +/- 2
	450	89 +/- 2
Cu: <45 (m	200	76 +/- 2
	450	78 +/- 3
Zn: <10 (m	200	62 +/- 5
	450	64 +/1 3

The RH tends toward a slightly higher value at the higher pressure for thicker spray-form buildup as might be expected.

Metallurgy -- Samples were prepared for metallurgical evaluation by cross-sectioning, polishing, and etching. Most of the preliminary microscopy work on these samples was performed with a scanning electron microscope. This was done to produce maximum contrast between individual powder particles in the deposits. These images will serve as input for computer modeling work on the KEM process that will be performed by LLNL and ITI during this fiscal year.

Some of the metalography samples were not completed at the time this paper was prepared, but will be included in the presentation of the paper.

a). Cu on Al -- Figure 3 (finer powder) and Figure 4 (coarser powder) contain SEM micrographs at 400X. These limited, preliminary data suggest that smaller particles produce deposits with lower porosity. These results were confirmed by gravimetric means. The bond between the coating and substrate seems more substantial for the larger particle size sample. Figure 4 shows individual powder particles embedded in the substrate. The lower portion of these particles show a contrast change that may indicate diffusion of Al (from the substrate) into the Cu particles. The chemistry of these particles will be studied with microbeam analysis in a follow on program.

Figure 3 shows what appears to be a porous layer or debonding phenomena at the deposit/substrate interface, though this preliminary result may be an artifact of sample preparation or the use of the SEM for these micrographs.

Figure 5 (finer powder) contains a higher magnification (4,000X) SEM micrograph which shows excellent particle-to-particle contact for the bulk deposit.

Figure 6 contains a group of 3 optical images (20X, 40X, and 125X) of finer powder. A dark band just above the deposit/substrate interface has not yet been identified. We hope to study this phenomena and others with more detailed optical metallography.

b). Zn on Al -- Figure 7 (finer powder), SEM micrograph (4,000X) shows a higher density deposit than that of Cu and excellent particle to particle contact. Note that white spots are thought to be Al_2O_3 polishing compound embedded in the soft Zn.

c). Ti on Al -- Samples currently in preparation.
d). Cu on Cu -- Samples currently in preparation.

Conclusions

This is an on-going project and additional data analyses are being performed. These include additional powders (Al, Ni, and Ti) applied to Al substrate, as well as a few other substrates such as Inconel-600 and Cu. SEM analysis of these samples is in progress. The following preliminary conclusions for the KEM process are noted.

Both the thin and bulk deposition have been successfully made using various powders.

Very reactive Ti powder (<45 (m) has been successfully deposited using helium gas. Ti powder was studied as a surrograte material for potentially performing KEM depositions of U powder.

Improvement in the deposition rate is expected with upgrades to the laboratory powder feeder configuration.

Significant improvements in the deposit properties (i.e., zero porosity, stronger bonding with the substrate material, etc.) will require use of the oxide-free or annealed powders. The powders used for the current series are commercial products believed to be generated by a cold-crushing process resulting in a work-hardened state.

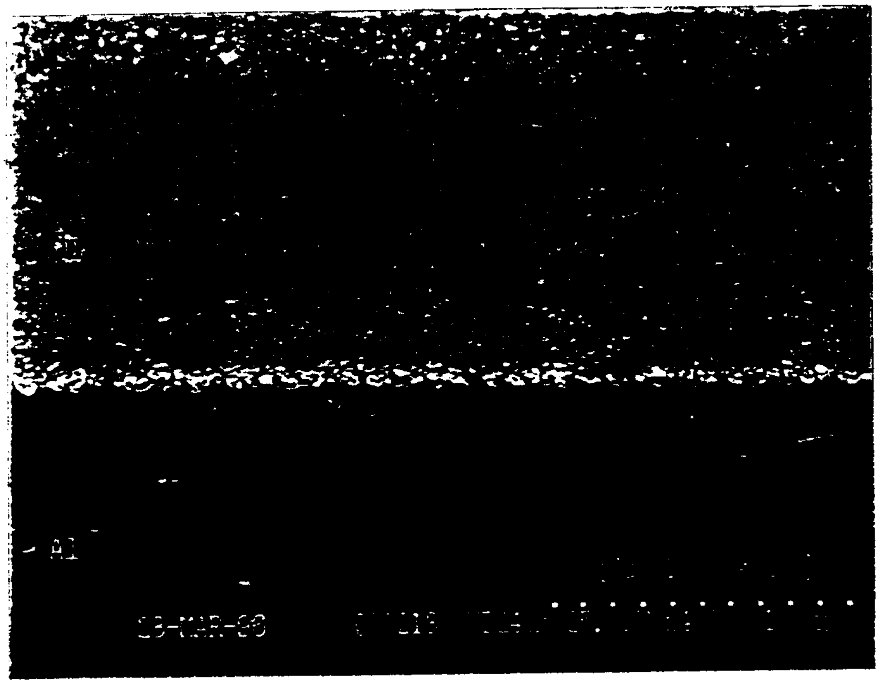


Figure 3 SEM Micrograph (X400) of Cu <10μm on Al

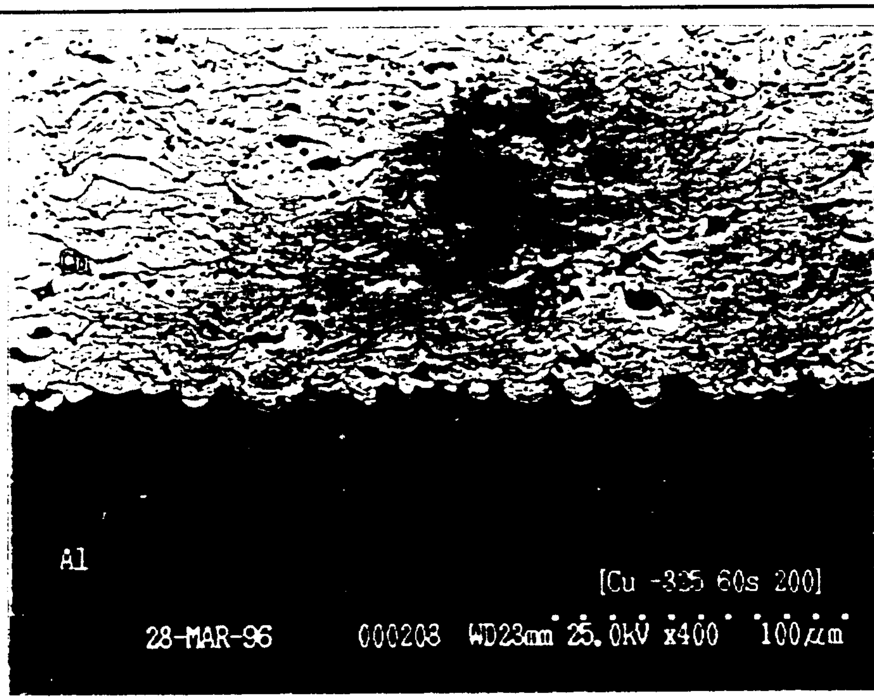


Figure 4 SEM Micrograph (X400) of Cu <45μm on Al

Figure 5 SEM Micrograph (X4000) of Cu <10μm on Al

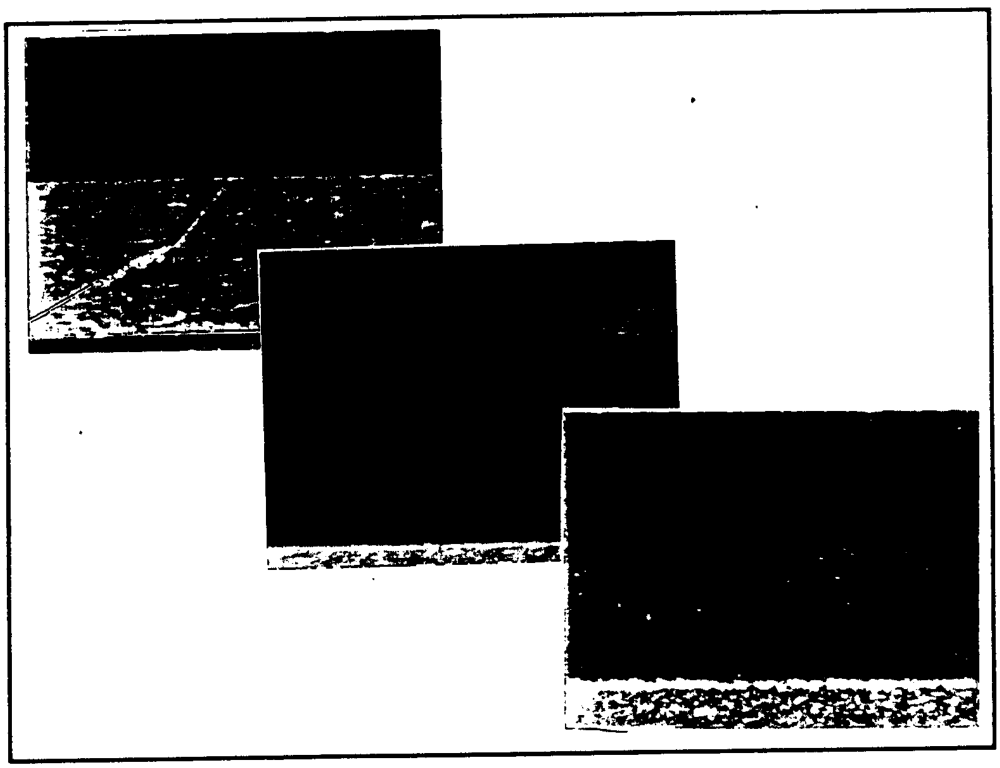


Figure 6 Optical Micrograph (X20, X40, X125) of Cu <10μm on Al

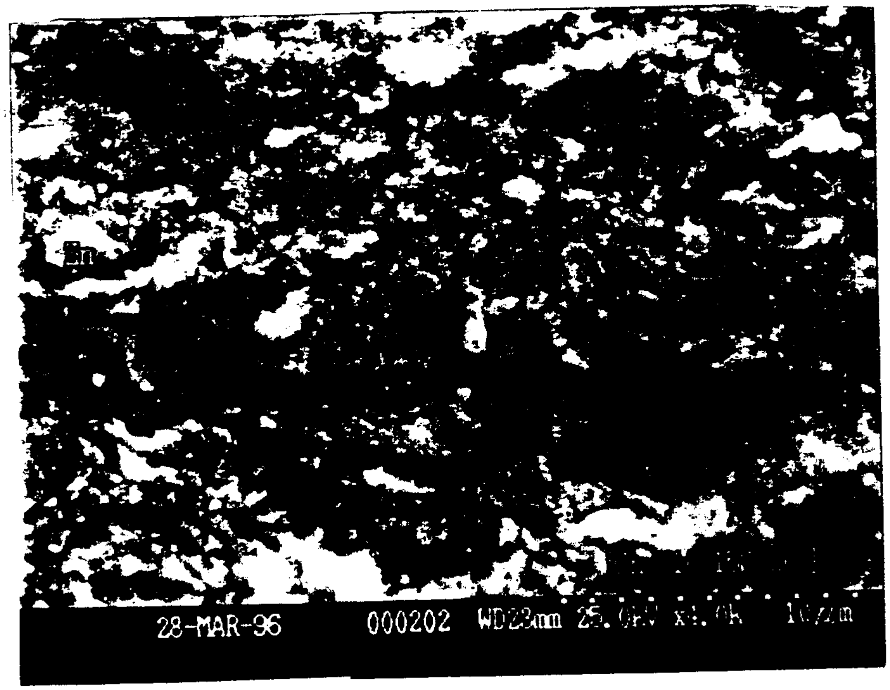


Figure 7 SEM Micrograph (X4000) of Zn <10μm on Al