# Advanced Materials Development White Paper

## *Allomet EternAloy® Tough-Coated Hard Powders (TCHPs): Advanced Nano-engineered Material Solutions For Extreme Wear Resistance Applications*

### Allomet TCHP Wear-Resistant Material Technology

Allomet Corporation has developed, tested, patented, and launched commercial production of a nano-engineered powdered metal product line called EternAloy® Tough-Coated Hard Powder (TCHP). Allomet's TCHP materials have excellent combined hardness and toughness properties that deliver extreme wear resistance and unique thermal management characteristics in surface coating and solid body applications. TCHPs serve as excellent solutions for a wide range of high-value industrial applications requiring extreme levels of reliability, productivity, and safety performance.

Specifically, TCHP technology enables the precision coating of micrometer-sized hard particles with a tough nanometer- thick protective shell (typically tungsten carbide or titanium carbonitride) covered with a strong binder layer (typically cobalt or nickel) less than 1 µm in thickness as shown in Figure 1, below. When sintered or applied using thermal spray methods, the tough outer layers chemically bond in the sintered article or deposited coating, combining high strength, heat resistance, and toughness of cemented carbides with the chemical and abrasion wear resistance of the harder core particles.

Allomet's proprietary TCHP production equipment enables nearly unlimited combinations of core particles, protective shells, and binders at previously unattainable nanoscale levels. TCHP made with over 30 types of core particles and related processing methods are covered under Allomet's patent portfolio. Current commercial offerings include coated titanium carbonitride (Ti(C,N)), alumina ($Al_2O_3$), silicon carbide (SiC), cubic boron nitride (cBN), and diamond particles. The performance envelope of the TCHP product family is shown in Figure 2 (below).

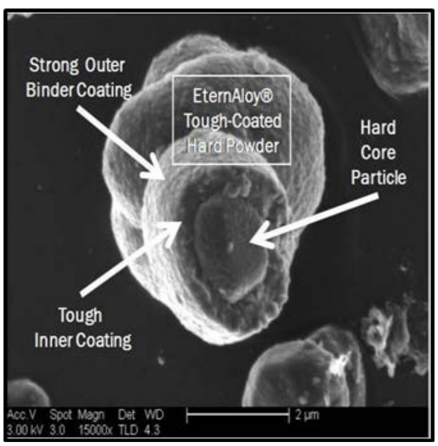


**Figure 1. Electron Microscope Image of Intentionally Fractured TCHP Particle**

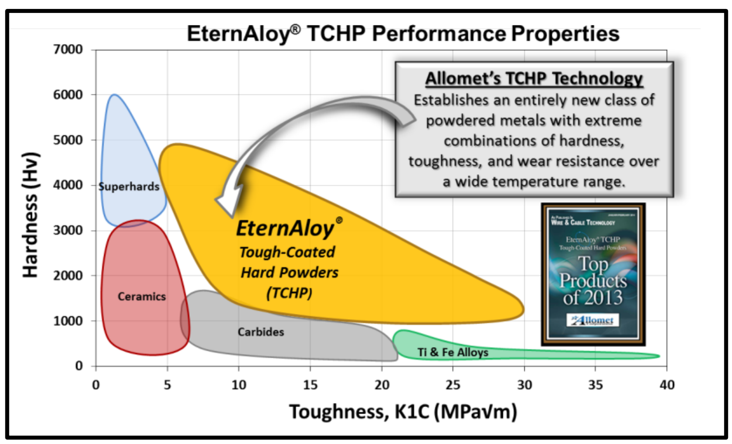


**Figure 2. TCHP "Combined Hardness vs. Toughness" Characteristics**

TCHP overcomes the inherent limitations associated with the mixing and blending of cemented carbide powders. Many other companies have tried to obtain the combined hardness and toughness needed for many industrial applications. Allomet has succeeded where others have failed. Allomet's technology provides a uniform distribution of cobalt (or nickel) in optimal amounts throughout a consolidated article or surface coating. Among other advantages, it avoids non-uniform distribution of the binder, the need for high sintering temperatures, WC grain growth and other causes of microstructural defects seen in conventional cemented carbides.

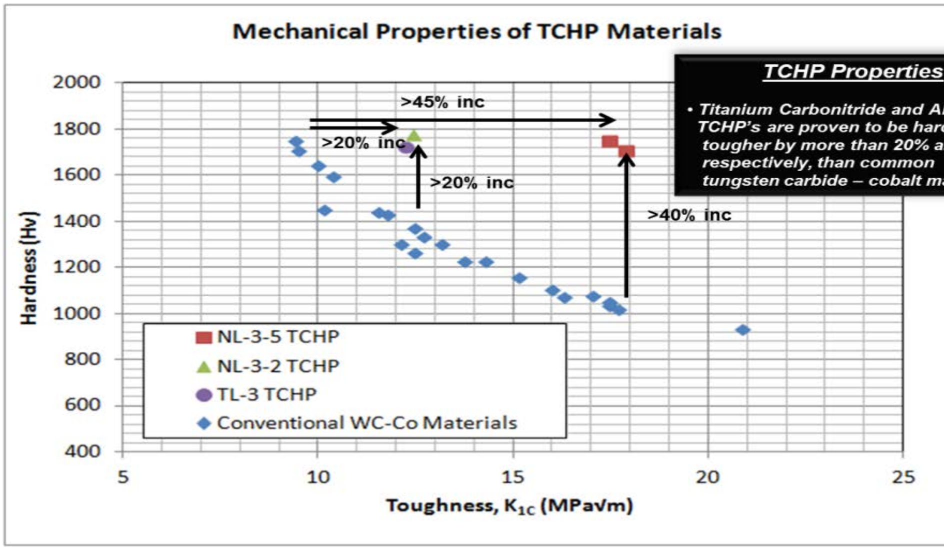


**Figure 3. TCHP Mechanical Property Improvements Versus Tungsten Carbides**

As shown in Figure 3 (above), the combined hardness and toughness of TCHP grades are significantly higher than conventional WC-Co materials. For example, a TCHP grade using 5-µm $Al_2O_3$ core particles (Allomet's grade NL-3-5) exhibits 45% greater toughness and 40% higher hardness than the conventional WC-Co cemented carbide grades. Two other grades using 2-µm cores ($Al_2O_3$ or Ti(C,N)) possess about 20% improved hardness and toughness over conventional WC-Co cemented carbide grades. It is important to note that the $Al_2O_3$ and Ti(C,N) grades exhibit different thermal conductivity characteristics, as shown in Figure 4 (below). The ability to alter these key performance characteristics through core particle changes and binder content (typically cobalt or nickel), further highlights the flexibility of TCHP technology and the opportunity to customize a solid article or coating for nearly any application.

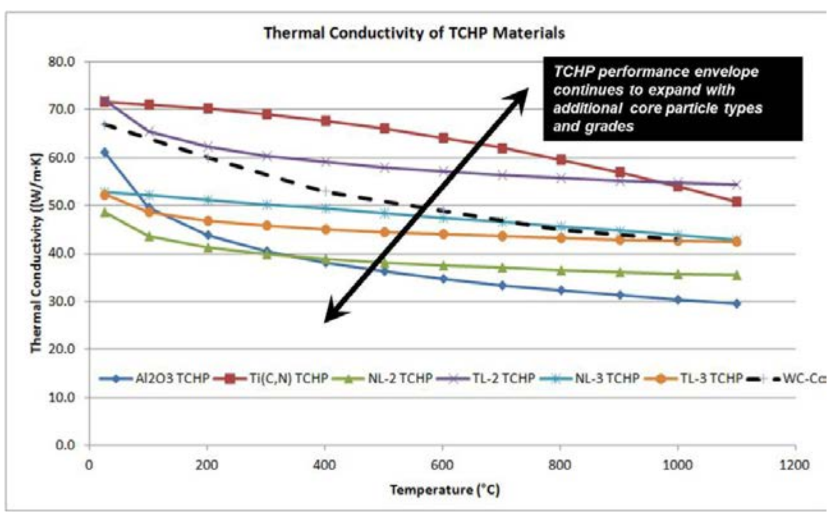


**Figure 4. TCHP Thermal Conductivity Properties**

TCHPs have been successfully applied as a surface coating using HVOF, laser metal deposition, plasma spray and other coating methods. The extremely high microhardness, strong adhesion to substrates, and low porosity attainable in thermal spray and laser metal deposition coatings deliver significant advantages in performance in demanding environments over a wide range of operating temperatures. With a variety of hard core- particles to choose from, TCHP grades offer customizable hardness, toughness, strength, wear-resistance, thermal conductivity, and lubricity, in addition to other desired performance properties. It should also be noted that TCHPs can be pressed and hardened into solid shapes via sintering in conventional furnaces commonly used to solidify industrial tungsten carbide (WC) powders.

Perhaps one of the strongest features of the unique TCHP production technology is the wide variety of compositions and sizes of powder particles it can provide. Allomet's manufacturing technology can meet the needs of practically any critical high-value customer application by combining a variety of materials with property extremes at the nano-scale.

Privately-held Allomet's custom-designed production facility is located near Pittsburgh, PA.

## TCHP Performance Testing of HVOF Applied Coatings

- ***Sliding Wear Performance at 700°F – Metcut Research (Cincinnati, OH)***

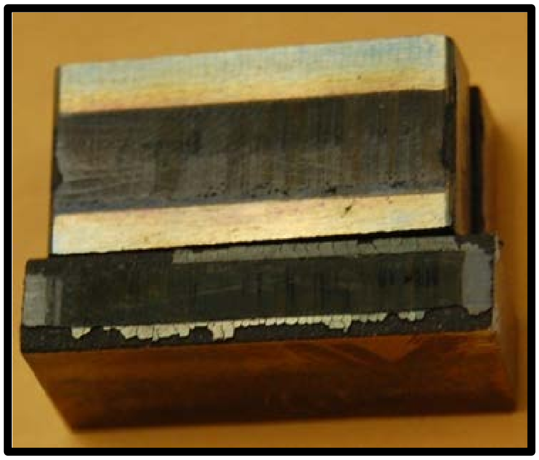

**Figure 5. Allomet TL-3 TCHP**
***((Ti(C,N) core + WC Shell + Co Binder)***
***Subjected to step-loading using a 5 Ksi and 5,000 cycle interval and ending at 50 Ksi, 5,000 cycles.***

**Total System Wear = 0.0001 in**

**Figure 6. T-800**
***(Leading Aerospace Coating)***
***Subjected to step-loading using a 5 Ksi and 5,000 cycle interval and ending at 45 Ksi, 5,000 cycles.***

**Total System Wear = -0.0448 in**

- ***Reciprocating Wear Test – GE Aviation Global Research Center (Bangalore, India)***

Testing of Allomet's TCHP TL-3 grade (Ti(C,N) core with WC and Co coatings) was performed at GE Aviation's Global Research Center in Bangalore India. The tests compared Allomet TL-3 against itself, against L605, and T-800 against L605 (Co-superalloy) to ascertain basic wear characteristics. Two test methods were used; reciprocating and ball on disk wear tests. Reciprocating wear tests were performed at 600 °F, with an applied stress of 2.5 Ksi, with a reciprocating stroke and frequency of 40 mils and 35 Hz, respectfully for 1 million cycles.

Preliminary results showed that self-mated TL-3 performed ~3.5x better than L605 vs T800 under the same test conditions, as shown in Figure 7 and Figure 8. Additional tests of the same material couples by ball on disc were performed with an initial contact stress of 7 Ksi, and sliding velocity of 2 in/s. The temperature was cycled from 150 to 550 °F, for 19.7K inches each. Wear was only measurable on the pin, as the disk wear was less than 0.04 mils. The wear showed the same positive results as the reciprocating wear test, with little to no wear for the self-mated Allomet coating compared to the L605 pin which presented with higher wear against either coating.

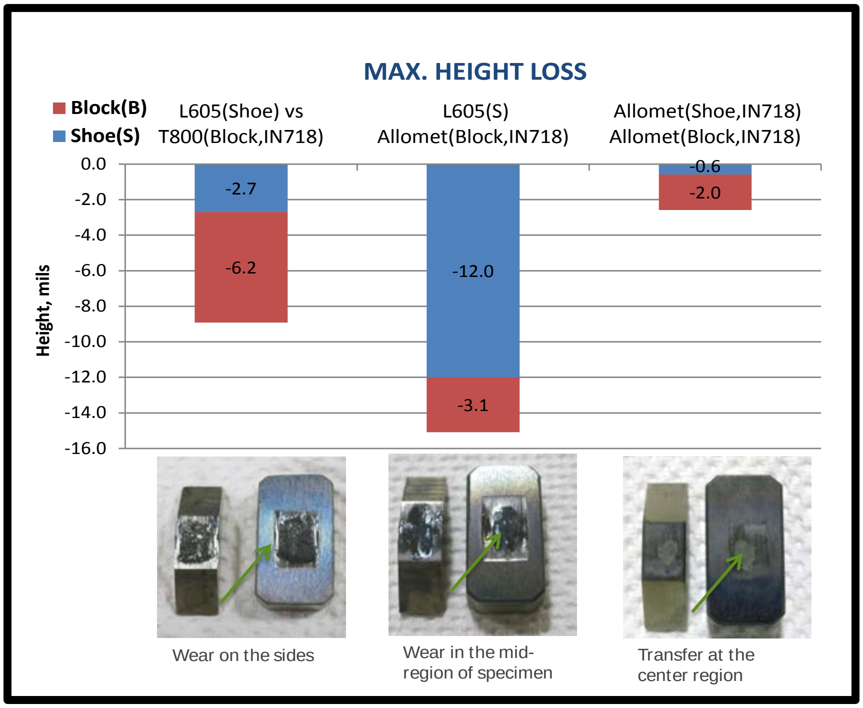


**Figure 7. Reciprocating Wear Tests**

*Reciprocating wear tests performed at 600 °F, 2.5 Ksi, 40 mils peak-to-peak, 35 Hz for 1,000,000 cycles*

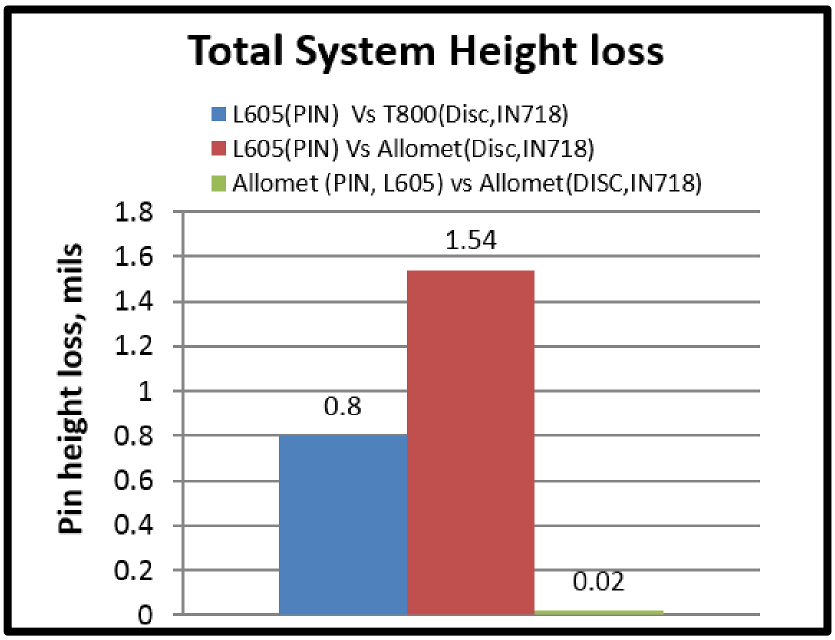


**Figure 8. Ball-On-Disk Wear Test**

*Measured wear on pin after ball-on-disk wear testing after thermal cycling tests at ~7 Ksi, for 19.7K inches at 150 followed by 19.7K inches at 550 °F*

Although these were single wear tests per material couple, with the test temperature being lower than T-800 optimal usage (>800 °F), testing suggests that TL-3 performance at temperatures below 800 °F could be superior to other low temperature tribological coatings. These novel core-shell powders, after application by HVOF, show promise to improve coating hardness, fracture toughness and tribological properties over current conventional tribological coatings. Additional testing of these coatings for application in the aerospace industry and comparison to coatings for moderate temperature usage is recommended.