

# Plasma Transferred Arc Overlays Reduce Operating Costs in Oil Sand Processing

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The use of the plasma transferred arc welding (PTAW) process using tungsten carbide (WC) bearing materials has provided considerable economic benefits in extending the service life of production equipment. This paper will focus on applications that have proven successful in reducing wear in the oil sand environment. We provide an overview of material testing and development for the overlays used. Tungsten carbide development includes the use of eutectic, macrocrystalline and spherical carbides using a nickel/boron/silicon matrix. As a result of laboratory evaluations and preliminary field trials, we have shown that engineering a specific alloy system for each application provides unique benefits. For example macrocrystalline carbides can be superior in low stress abrasive environments, while eutectic carbides with modified matrices are often best suited to high stress abrasive environments, such as experienced by crusher parts. We provide specific case studies with cost savings illustrating the significant economic value of PTAW overlays. Specific applications discussed are ground-engaging parts used in traditional mining and earth-moving equipment, crusher and sizer apparatus, as well as other applications directly related to extraction and processing equipment.

Oil sand extraction and processing demands continuous testing and improvement of new materials and PTAW processing techniques. In today's competitive environment, these lessons are vital for all industries that experience severe abrasion and erosion problems, and where reducing downtime and maintenance costs is paramount.

## 1 Introduction

Oil sand processing is a rapidly expanding industry in Canada. Canadian oil sand reserves contain an estimated 2.5 trillion barrels of oil [1], which exceeds known conventional oil reserves in Saudi Arabia by up to 5 times. Oil sand deposits are located in the Athabasca region of northern Alberta, which currently produces 130 million barrels of oil annually, with expected increases to 650 million barrels by 2010.

Oil sand extraction (see Figure 1) is primarily an open pit mining operation that uses 45 cubic metre shovels to extract the ore from the ground, while 400-ton trucks haul the ore to the crushers for crushing and sizing. The oil sand is then conveyed to a cyclofeeder that combines the oil sand with warm water (25°C) to create a slurry that is pumped via pipeline to the extraction and upgrading facilities. The bitumen is extracted from the oil sand by warm water and caustic soda in large separation vessels. The sand settles out and the bitumen forms a froth that is removed for processing. Secondary separation and processing converts the tar-like oil to a straw-colored crude oil that is low in sulfur. For every barrel of refined oil produced, two tonnes of oil sand has been processed [2].

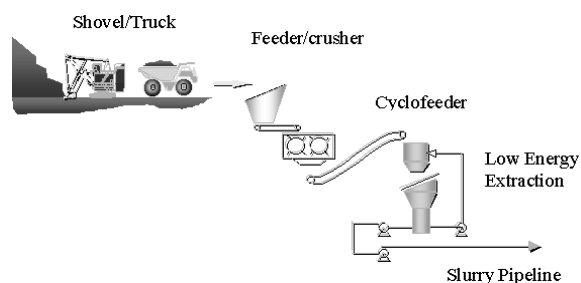


Fig. 1. Oil Sands Mining Process [3]

Wear protective overlays are essential for reliability in production processes. Without protecting components that handle the oil sand, production goals would not be met. Without production goals being met, profits for the shareholders would not be realized. Wear protective overlays help make the process economically viable.

Application development is widespread, but can be classified into these areas:

- Mining and ground-engaging equipment
- Crushing and sizing equipment
- Material handling equipment
- Slurry pumping and pipeline components
- Separation and centrifuge equipment

## 2 Overview of Wear Protective Technologies

Oil sand processors employ all wear protective technologies, and each contributes specific advantages for the various applications. They are:

- Welded Overlays
- Casting & Foundry Technologies
- Brazed Overlays
- Heat Treatment / CVD / PVD Processes
- Thermal Spray Coatings
- Electro-Mechanical Plating

Of these, the first two: welded overlays and casting technology are used more often. In order to optimize performance, a combination of these technologies can be employed, sometimes on the same component.

Welded overlays can be further broken down by process:

- Rod and Powder Brazing (RB & PB)
- Flux-Cored Arc Welding (FCAW)
- Shielded Metal Arc Welding (SMAW)
- Plasma Transferred Arc Welding (PTAW)

While Messer Eutectic Castolin is involved with all of the aforementioned processes, this paper will only focus on the PTAW process.

## 2.1 Overview of Plasma Transferred Arc Welding

PTAW is a welding process where a high-energy transferred arc is created between the torch head (anode and cathode), and the base metal forming a liquid puddle. Inert gas, most commonly argon, is introduced into the electrical arc producing a plasma column. Powdered alloy is fed into the plasma column and is melted into the substrate, metallurgically bonding to the substrate.

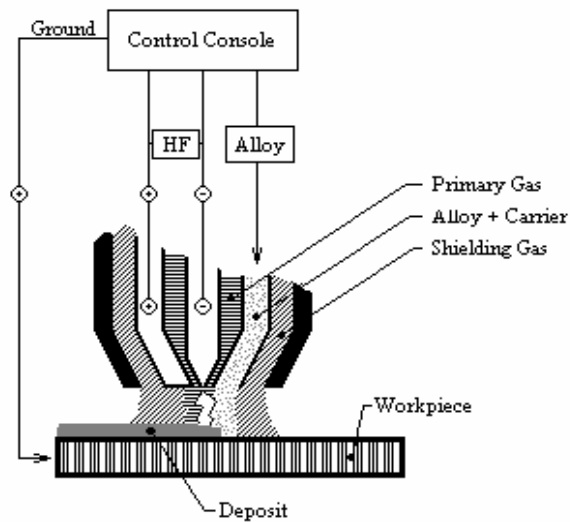


Fig. 2. PTAW Process

PTAW has the following advantages:

- High deposition rates (up to 25 kg/hr)
- High deposition efficiency (approx. 85%)
- Low dilution with the base metal (generally less than 10%)

The degree of dilution is dependent upon substrate type and mass, and welding parameters. A low dilution factor ensures that the overlay alloy achieves the required wear resistance properties in just one pass. This can be significant in terms of economics when compared to other arc welding processes that may require up to three weld passes to eliminate the negative effect of dilution.

In addition, PTAW allows the user many advantages in selecting coating properties. Because PTAW uses powdered alloy feedstock, customizing material properties to the intended application is relatively easy. In general, metal matrix composites (MMC'S) are used for wear related applications. The MMC's have a nickel-based (metal) alloy for the matrix material and tungsten carbide (composite) for optimum wear resistance. The size, quantity and morphology of the tungsten carbide have unique properties, which must be customized to the specific use. Similarly, the correct choice of matrix materials

plays a great role in wear properties because they can form secondary hard phases in the finished product. A direct correlation exists between application criteria; material development and PTAW weld parameters to obtain optimized wear resistance.

## 3 Results

Two forms of eutectic carbide ( $W_2C$ -WC) have been evaluated – angular and spheroidal. In addition a macrocrystalline carbide (WC) was evaluated. The test matrix also assesses the wear resistance of two different matrix alloy chemistries and hardness's.

Table 1. Sample Characteristics

	A	B	C	D
<b>Carbide Type</b>	Eutectic ( $W_2C$ -WC)	Eutectic ( $W_2C$ -WC)	Eutectic ( $W_2C$ -WC)	Macro - crystalline (WC)
<b>Morphology Matrix</b>	Angular NiBSi	Spheroidal NiBSi	Angular NiCrBSi	Angular NiBSi
<b>Matrix Hardness (Rc)</b>	45	45	53	45
<b>Carbide/ Matrix (Vol.%)</b>	60/40	40/60	60/40	65/35

Figure 3 shows typical angular eutectic carbides. It was observed that the carbides lose their angularity at high amperage.

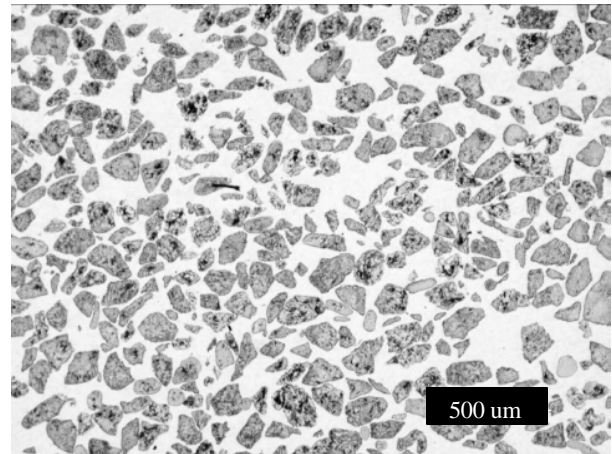
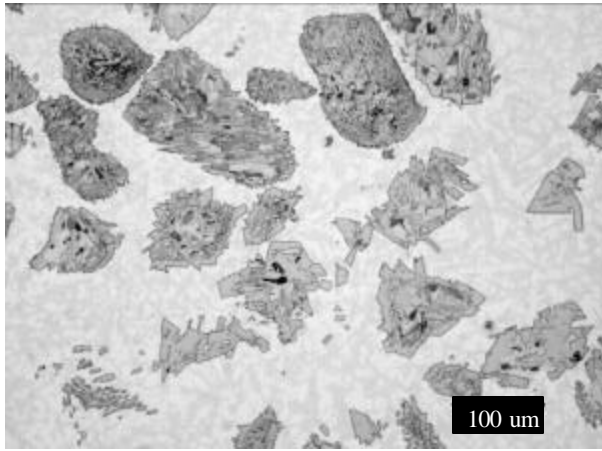
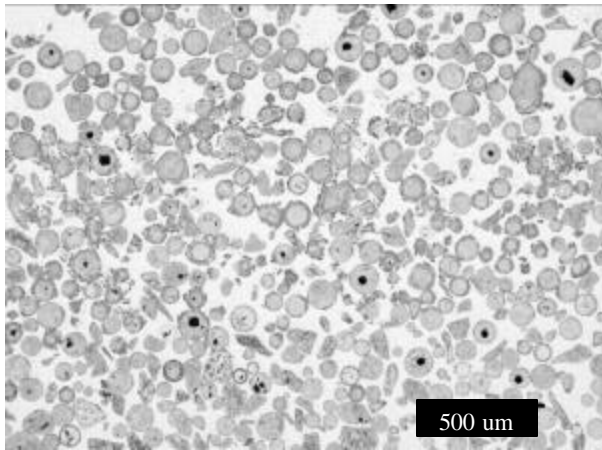


Fig. 3. Sample C 140 Amps



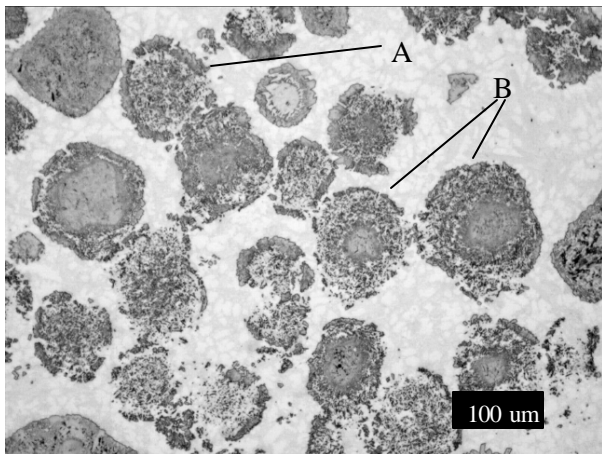
**Fig. 4.** Sample C 160 Amps

At higher amperages, the eutectic carbides are undergoing dissolution as shown in Figure 4.



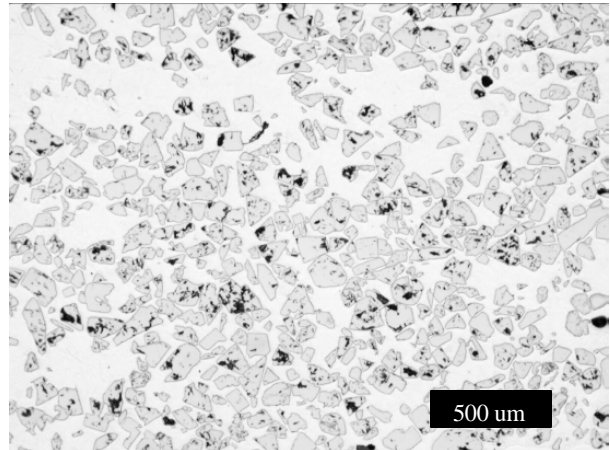
**Fig. 5.** Sample B 140 Amps

Figure 5 shows eutectic spheroidal carbides evenly distributed.



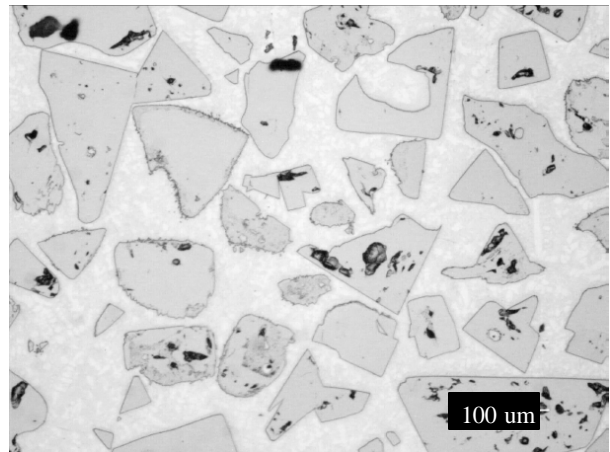
**Fig. 6.** Sample B 140 Amps

Figure 6 shows evidence of a dissolution zone around carbides (A). Reprecipitation around some carbides was observed (B).



**Fig. 7.** Sample D 160 Amps

Sample D contains a macrocrystalline carbide (WC) with an angular morphology. There is some evidence of non-uniform mixing during welding. Minimal dissolution has occurred at high amperage as seen at the surface (top of Figure 7).



**Fig. 8** Sample D 160 Amps

At higher amperages (up to 180 amps), the macrocrystalline carbides resist dissolution as shown in Figure 8.

### 3.1 Wear Test Results

The ASTM G65 Dry Sand/Rubber Wheel abrasion test standard Procedure A was used. A first test of 6,000 revolutions (standard Procedure A) is followed by a second 6,000 revolution test (non-standard modified Procedure A) into the previously existing wear scar. The second 6,000 revolution test is performed in order to understand the non-linear wear rates of metal matrix composite materials. In general, the first test is highly non-linear and steady state conditions are only achieved after an initial "run-in" period. This

phenomenon is due to the hard and soft dual phase structure in the microstructure. The samples were given sufficient time to cool prior to the second run. The wear tests indicate that the macrocrystalline carbide chemistry offers superior wear resistance compared to eutectic carbide. The harder chromium containing matrix performs better than the chromium-free matrix alloy. Angular eutectic carbides perform better than spheroidal eutectic carbides.

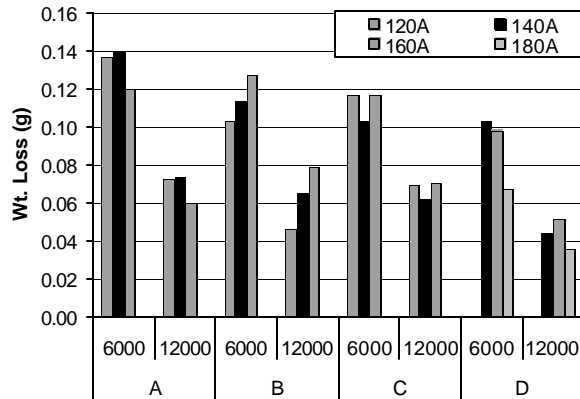


Fig. 10. ASTM G65A Wear Test Data

#### Sample A

Wt. loss follows an approximate decreasing linear trend with increasing amperage. Wt. loss results for the second wear test average 52% of the weight loss for the first wear test.

#### Sample B

Wt. loss shows an approximate increasing linear trend with increasing amperage. Wt. loss results for the second wear test average 55% of the weight loss for the first wear test.

#### Sample C

Wt. loss follows an approximate increasing linear trend with increasing amperage. Wt. loss results for the second wear test average 60% of the weight loss for the first wear test.

#### Sample D

Wt. loss follows an approximate increasing linear trend with increasing amperage. Wt. loss results have for the second wear test average 50% of the weight loss for the first wear test. It was observed that weight loss is lower relative to eutectic carbide samples.

## 4 Discussion

The application of tungsten carbide nickel based alloy composites by PTAW involves application of the powder feedstock into a transferred (from cathode to workpiece) plasma arc of up to 18000 K. The powder is fed into the vicinity of the arc, but is not fed through the arc as in FCAW or GMAW, for example. The powder consumable is easily altered to give optimum characteristics. For example carbide loading, carbide type, matrix alloy chemical composition, and carbide morphology can easily be changed to give different microstructures and the resulting wear resistance that is required for a particular application. For these reasons, PTAW application of WC/Ni alloy composites is the preferred method. Simultaneous spray fusion is a complimentary process used where relatively thicker deposits are required [4].

Large parts and stringent delivery requirements require high welding production rates and therefore high powder delivery rates. In order to ensure base metal fusion, PTAW requires higher transferred arc currents. With a higher thermal input, higher powder feed rates can be used. However, the results indicate that as the transferred current amperage is increased (while maintaining the powder feed rate, voltage, oscillation parameters and travel speed all constant), the carbides will start to undergo dissolution, particularly towards the deposit surface. Dissolution of the  $W_2C$ -WC structure results in tungsten and carbon going into solution in the nickel alloy matrix, resulting in reprecipitation of various undesirable complex carbides upon cooling of the weld pool. Reprecipitation generally occurs heterogeneously onto previously existing carbide particles, resulting in the "halo" effect noted in the photomicrographs (see Figure 6). A parallel effect is an overall hardening of the matrix alloy due to super saturation of tungsten and carbon. This hardening can be beneficial in regards to wear resistance assuming that the impact conditions are mild. However, with impact conditions, a hardened matrix may begin to fail from mechanisms other than wear.

It was observed that eutectic spheroidal carbide undergoes dissolution much earlier than eutectic angular carbides. Additionally, only spheroidal carbides were observed to undergo dissolution within the centre of the sample where the oscillation pattern of the welding torch may affect the local heat input. Macrocrystalline tungsten carbide offers more resistance to dissolution. Wear resistance is also superior compared to eutectic carbide. The impact resistance of these samples has not assessed at this time.

The differences in wear resistance based on matrix chemistry/hardness can be assessed by comparing Sample A and Sample C wear test data. Little difference can be seen based on these wear results. The addition of chromium into the nickel alloy matrix produces an increase in the hardness. There may be a small decrease in the weight loss but further data is required for confirmation.

## 5 Field Tests and Case Studies

Testing and application development is continuous and ongoing with many applications already proven and in use. To be economically feasible and as a minimum requirement, PTAW overlays generally should have 2 times the service life of the previous wear protective technology used. This economic criterion is used as a benchmark when evaluating future applications.

### 5.1 Dragline Bucket Tooth:

Draglines are still used but will eventually be discontinued and converted to a truck and shovel operation. There are 6 teeth to a bucket with each tooth weighing 165 lbs. An example is shown in Figure 11.



Fig. 11. Dragline Bucket Tooth

Solution	Previous	Current
Overlay Process	FCAW	PTAW
Overlay Material	CrC	WC NiSiFeB
Life Extension	100%	300%
Savings/Bucket/Year*	-	\$180,000

### 5.2 Summer Grader Blade Cutting Edge:

CATERPILLAR® 16G and 24H graders are used to maintain roadways both in the open pit mine and in the reclamation areas. These graders operate on virgin oil sand as well as hard-packed haul roads. With the application of a WC overlay to the blades, the end user is expected to save over \$250,000 per grader per year using summer and winter grader blade cutting edges. An example is shown in Figure 12.

Solution – summer	Previous	Current
Overlay Process	-	PTAW
Overlay Material	-	WC NiSiFeB
Life Extension	100%	700%
Savings/Grader/Season*	-	\$115,000

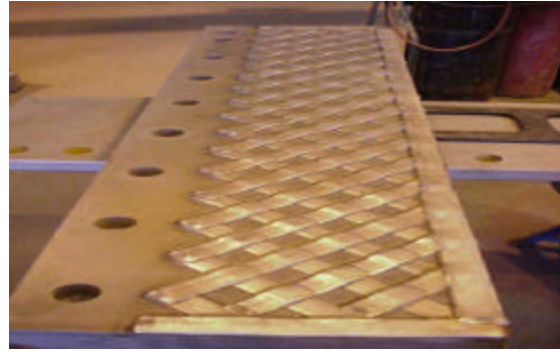


Fig. 12. 16G Summer Cutting Edge

### 5.3 Double Roll Crusher Tooth:

Crusher teeth are used to break up the oil sand feedstock, prior to the screening process. The teeth are mounted on two counter-rotating rolls, which reduce the incoming ore to approximately 100mm in diameter. There are 108 x 40 lb. teeth per roll, for a total of 216 teeth per crusher. An example is shown in Figure 13.



Fig. 13. DRC Tooth

Solution	Previous	Current
Overlay Process	FCAW	PTAW
Overlay Material	CrC	WC NiSiFeB
Life Extension	100%	500%
Savings/Crusher/Year*	-	\$370,000

### 5.4 Hydrotransport Screens:

A series of screens is used to remove lumps of oil sand that are larger than 100mm. Initially manufactured from CrC submerged arc wear plate, they are now supplied as WC overlaid HSLA steel. There are up to 66 different screens per system, with 3 systems running 24 hours per day. An example is shown in Figure 14.





**Fig. 14.** Hydrotransport Screen

Solution	Previous	Current
Overlay Process	SAW	PTAW
Overlay Material	CrC	WC NiSiFeB
Life Extension	100%	500%
Savings/System/Year*	-	\$0

### 5.5 Secondary Breaker Hammer:

This is a secondary crusher which re-crushes oversized ore that has been rejected after the screening process. Each hammer weighs 190 lbs and there are 26 hammers per unit. An example is shown in Figure 15.



**Fig. 15.** Secondary Breaker Hammer

Solution	Previous	Current
Overlay Process	-	PTAW
Overlay Material	-	WC NiSiFeB
Life Extension	100%	500%
Savings/Breaker/Year*	-	\$440,000

\* All savings listed are for initial component savings only. This amount does not include savings from reduced labour costs, increased equipment uptime, reduced spare parts inventory costs etc.

As part of the continuous improvement of PTAW overlays and applications in the oil sands industry, the following applications are currently being tested and monitored:

- conveyor belt cleaner disc
- dragline bucket shroud
- scoop tram cutting edge
- shovel bucket runner
- heel band wear block
- various wear plates and blocks

## 6 Economic Benefits of PTAW MMC's for Wear Protective Overlays

On the surface PTAW wear protective overlays using WC would seem more expensive than other materials or technologies. However we need to compare more than just the initial component cost to realize the full economic benefits. To do that a broader understanding of the accrued savings are necessary. In-depth study of these applications found that often the largest cost in the replacement of wear components is not the component itself, but the costs associated with changing the component. Therefore it is necessary to evaluate economic value as follows:

- 1) Initial component cost: This cost only considers the initial cost of a component, which includes the raw component (cast or fabricated), plus the cost of any wear protective overlay or treatment. Until recently two factors contributed to higher costs, raw material prices and PTAW processing costs. Both have improved greatly to help reduce processing costs [5], making PTAW - MMC's more competitive.
- 2) Component life cycle cost: This cost (usually measured in \$/hour or \$/tonne), is the relationship between the initial cost of the component and the total cost when service life is considered. This ratio is the true measure of what components cost, within the context of its useful life.
- 3) Other cost savings directly attributable to component life cycle: extending a component life cycle has a direct impact on other costs associated with maintenance and safety issues. They are:

- Reduced labour costs associated with component changes
- Reduced spare parts inventory costs, storage costs and transportation costs
- Increased equipment up time or less downtime (non-productive time). The equipment simply runs longer between shutdowns
- Reduced component weight due to extended service life. PTAW overlays 3.0mm thick can outlast CrC overlays 12mm thick. Parts can be reengineered to remove mass no longer necessary

- Increased safety due to the reduced number of components handled and the reduced weight of those components. A safe work environment also increases manpower productivity
- 4) All of these savings have a “trickle-down” effect:
- Lower Operating Costs
  - Higher Productivity
  - Lower Inventory Costs
  - Increased Profitability

## 7 Summary

The use of PTAW has already proven a reliable weapon in reducing wear in the oil sands industry. Based on the applications highlighted in this paper, as well as other on-going research and testing, we have concluded that material selection, PTAW processing parameters and overlay designs must correlate to the intended application.

Eutectic WC overlays are widely used due to their predictable behavior in service, and because they are readily available to the global market at a low cost to performance ratio. However research suggests that the use of macro-crystalline WC can be better in low angle, low stressed abrasive applications. Field-testing of this material will be continued to determine its value in service conditions. While spherical carbides did not substantially increase wear resistance, we do acknowledge some benefit in high impact applications, or where a coating of higher WC density is required.

The economic value of PTAW coatings continues to improve because of new material development, new high production PTAW equipment, lower raw material costs, and the related “trickle-down” effect of cost savings. As acceptance grows, confidence increases, and more parts using WC – MMC’s are put into service. These findings together with more work on WC and matrix materials will be reported in future technical papers.

## 8 Acknowledgments

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## 9 Literature

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