EVALUATION OF COATINGS FOR RESISTANCE TO ABRASIVE AND ADHESIVE WEAR IN PUMP COMPONENTS

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ABSTRACT

Long term pump efficiency and durability are directly related to the ability of materials of construction to resist various forms of wear. The need for resistance to both adhesive and abrasive wear is often greatest in wear rings and similar components, where close clearances must be maintained between rotating and stationary components. Insufficient resistance to adhesive wear will induce failure by galling or seizure in the event these components make contact. Inadequate resistance to abrasive wear will lead to rapid loss of clearances and drop in pump performance.

Traditionally, pump manufacturers have specified hardened martensitic stainless steels for critical wear parts, maintaining a 50-100 Brinell hardness difference between rotating and stationary components as experience has shown this is adequate to prevent galling. Coatings have been used to a limited extent, primarily in specialized applications, such as the plungers in reciprocating pumps. Selection of coatings has been hampered by a lack of reliable technical data on comparative performance. The result has been that a variety of coatings have been utilized by various pump manufacturers through the years, with mixed success and few documented case histories on coating performance.

INTRODUCTION

Coating technology has made rapid advances over the past decade. A limiting factor in the past has been inadequate bond strength between the coating and substrate. This deficiency has led to delamination, or peeling type coating failures in pump components, particularly those which can experience high shear stresses, such as wear rings, bushings, and sleeves. One objective of coating research has been to develop equipment which could apply higher quality coatings, having higher density and better adherence to the substrate. There has been notable success in reaching this goal, with the introduction of high velocity oxy-fuel (HVOF) spray guns. This equipment, as the name implies blasts a powder metal coating at very high velocity onto a substrate. High velocity spraying produces coatings with a significant improvement in wear resistance over plasma sprayed coatings. Tungsten carbide materials show improved wear resistance and coating durability when HVOF sprayed due to decreased carbide solutioning, higher bond strength and reduced porosity as compared with plasma sprayed coatings [1].

High velocity oxy-fuel type equipment has been developed and improved upon over many years. Initial hardware designs produced a pulsed jet and many benchmark coatings of high quality. Unfortunately, the equipment was cumbersome to use, which led its manufacturer to market coating services only, with the parts to be coated shipped to and from the equipment. In the early 1980s new continuous high velocity jet equipment was developed which could be hand held for use onsite for production applications. However, the water cooling required considerable support equipment, which limited its versatility. The latest generation of HVOF equipment is air cooled and both lightweight and completely portable. The gun can be hand held or fully automated with a robotic spray system. The air cooled equipment is capable of producing the same high quality coatings as its predecessor's in addition to new coatings developed for this equipment.

The introduction of HVOF and other novel surface treatment processes has generated considerable interest in the pump industry because these coatings offer the possibility to extend the life of components that suffer severe abrasive and/or adhesive wear. Recognizing both the opportunity to use new improved coatings, and the need for quantitative data on coatings in present use, a comprehensive program to characterize the resistance of representative coatings to both abrasive and adhesive wear was initiated. The intent was that the data be generated under carefully controlled laboratory conditions, followed by selected field exposure of the coatings showing best laboratory performance. The focus of this program was to identify optimum coatings for use in boiler feed pumps and similar applications where reduced tolerances between rotating and stationary components are desirable and resistance to both abrasive and adhesive wear should be optimized.

TEST RESULTS

Preliminary Screening

The initial phase of this program focused on a comparison between three cobalt- chrome, tungsten carbide coatings (stellite 1, 6, and 12),and a typical high velocity tungsten carbide coating. The stellite coatings were chosen on the basis of their widespread use in the pump industry. Each was applied using flame spray, plasma, and HVOF equipment. All the laboratory work involving HVOF coatings utilized Diamond Jet equipment, a versatile air cooled system with capabilities for manual, semiautomatic, and fully automatic use.

The coatings and methods of application included in this preliminary evaluation are listed in Table 1. Properties including hardness and as-sprayed surface finish are given for each of the coatings. Each was then compared to a standard nickel-chrome-boron coating (similar to Colmonoy 6) in an abrasive slurry test. The standard coating was flame sprayed and fused. Coating performance was evaluated qualitatively on the basis of change in mass and thickness. The best coating was the fused tungsten carbide which wore 80 percent better than the standard. The as-sprayed tungsten carbide provided 30-40 percent better wear than the standard. The only other material whose performance surpassed that of the standard was fused flame sprayed stellite 1, which wore 20 to 30 percent better than standard.

Table 1. Coatings and Methods of Application.

Coating	System	Macro Hardness	DPH Avg	DPH 300 Range	A/S Surface Finish	150 Grit Diam Surface Finish (Ground)
A/S Stellite SF*1	SP (1)	Rc 42-49			900-1200$_{AA}$	--
Fused Stellite SF1	SP	Rc 53-57	701	639-764	--	3-4$_{AA}$
A/S Stellite SF6	SP	Rc 41-46	628	224-810	700-1000$_{AA}$	--
Fused Stellite SF6	SP	Rc 49-51	510	461-548	--	3-4.5$_{AA}$
A/S Stellite SF12	SP	Rc 38-50	753	592-860	850-1150$_{AA}$	--
Fused Stellite SF12	SP	Rc 55-56	604	413-713	--	3.4$_{AA}$
Stellite 1	9MB(2)	Rc 44-46	419	312-488	190-250$_{AA}$	5-18$_{AA}$
Stellite 6	9MB	Rc 35-37	335	283-368	200-300$_{AA}$	14-17$_{AA}$
Stellite 12	9MB	Rc 37-39	349	291-376	220-290$_{AA}$	14-17$_{AA}$
Stellite 1	DJ(3)	Rc 56-58	702	523-900	300-375$_{AA}$	3.5-5$_{AA}$
Stellite 6	DJ	Rc 45-47	459	344-599	300-425$_{AA}$	3-5$_{AA}$
Stellite 12	DJ	Rc 50-53	558	472-665	450-575$_{AA}$	3.5-5$_{AA}$
A/S Diam 2002	DJ	Rc 53-54	635	478-743	250-350$_{AA}$	2.5-4$_{AA}$
Fused Diam 2002	DJ	Rc 66-67	710	499-915	--	2.5-4$_{AA}$

1) SP is Metco designation for flame spray gun.
2) 9MB is Metco designation for plasma gun.
3) DJ is Metco designation for HVOF gun.
* Denotes superfine powder.

It was concluded that the tungsten carbide coating (a 50/50 powder mix comprised of fine tungsten carbide, cobalt, and nickel chromium base powders) exhibited the best technical benefits including fine as-sprayed surface texture, finer ground finishes, ease of fusing, and lower wear rates. Comparing the microstructure of the fused coatings, the tungsten carbide was more dense and had less oxide inclusions than the flame sprayed stellite coatings. It also finished to a finer surface finish, because there was less particle pullout related to the oxide formation.

Based on these results, which are in agreement with published literature [2] on the properties of HVOF coatings, it was decided that conventionally applied cobalt base coatings are clearly inferior to high velocity tungsten carbide coatings. Consequently, the coating selection process for this program was modified to emphasize tungsten carbide coatings, while also including generic types identified as being in common use in the pump industry.

Final Selections

The coatings which were eventually selected for inclusion in this test program are listed in Table 2. Colmonoy 6 is a nickel base coating containing chrome boride and considered to be the industry standard for resistance to combined abrasive and adhesive wear. Metco 15E is similar to Colmonoy 6. Diamalloy 1008 is an iron-chrome base coating containing molybdenum/chromium carbides and developed as an alternative to chrome plating for sleeves, journals, and other bearing surfaces. Diamalloy 2001, 2002, 2003, 2004, 2005, and 2007 are a series of wear resistant coatings. The 2001 and 2002 are nickel base containing boride and tungsten carbide additions, respectively, while the 2003-2007 are essentially tungsten carbide containing varying amounts of cobalt binder. Diamalloy 4006 is a nickel base powder containing refractory metals and metalloids. It has a largely amorphous structure and is reputed to have excellent adhesive wear resistance. Diamalloy 3007 is a nickel chrome-chrome carbide coating. Metco 501 is a nickel-chrome powder containing 30 percent molybdenum for self-lubricating properties.

Table 2. Coating Properties.

Material	Generic Type	Method of Spray	Density (g/cc)	Porosity (Vol.%)	Average Macro (Rc)	Hardness Micro (DPH$_{300}$)	Bond Strength (PSI)
Colmonoy6	Ni-Cr-B	Flame-Fused	7.52	0.38	58	693	-
Metco 15E	Ni-Cr-B	Flame-Fused	7.64	0.16	56	775	-
Diamalloy 1008	Fe-Cr-Mo-B	HVOF-As Sprayed	6.65	1.70	45	300	9,420
Diamalloy 2001	Ni-Cr-B	HVOF-As Sprayed	6.86	0.74	51	596	10,832
Diamalloy 2001	Ni-Cr-B	HVOF-Fused	7.54	0.31	58	680	-
Diamalloy 2002	Ni-Cr-Co-WC	HVOF-As Sprayed	8.64	0.94	50	620	13,503
Diamalloy 2002	Ni-Cr-Co-WC	HVOF-Fused	9.23	0.47	60	710	-
Diamalloy 2003	WC-Co	HVOF-As Sprayed	13.79	0.50	61	932	11,261
Diamalloy 2004	WC-Co	HVOF-As Sprayed	12.64	0.50	58	855	11,285
Diamalloy 2005	WC-Co	HVOF-As Sprayed	12.60	0.50	59	942	11,104
Diamalloy 2007	WC-Co	HVOF-As Sprayed	11.24	0.50	54	849	12,276
Diamalloy 3007	Ni-Cr-CrC	HVOF-As Sprayed	6.13	1.10	62	728	11,340
Diamalloy 4006	Ni	HVOF-As Sprayed	7.72	2.20	45	-	11,987
Diamalloy 2001 +Mo	Ni-Cr-0B-Mo	HVOF-As Sprayed	9.13	1.20	50	-	8,482

Three unconventional coatings/materials were tested. These included chrome and titanium nitrides, both applied using a ion implantation based surface treatment. This process, carried out at less than 300°F, introduces hardening elements into surface layers of the material. These surface treatments were included because they offer the advantage of hardening a finish machined component, with no change in dimensions and no possibility of detachment of a mechanically bonded coating. The expected weakness is that only a very thin surface layer is hardened.

A metal filled graphite, was included in the tests intended to evaluate adhesive wear. This material is often used to combat severe galling problems in boiler feed pumps and could be considered as a benchmark against which the resistance to adhesive wear of coatings could be measured.

A number of other coatings were considered for testing but excluded for various reasons. Artificial diamond films were investigated but found to be too expensive. They also yield only a very thin coating (~1000 Å) not considered practical for use in pumps. There are also significant restrictions on the dimensions of the parts which can be coated.

A coating process known as Xuloy was also found to be not practical. This is a modification of ion implantation which offers thicker coatings. It required a high temperature carburizing treatment subsequent to surface treatment. This is not compatible with martensitic stainless steels and other heat treatable alloys which are primary candidates for coating. Boron and other gaseous diffusion processes were also rejected for the reason that they require high temperature which may be incompatible with the part to be coated.

Ceramic coatings were not tested. While they are routinely used on sleeves to resist packing wear, their use in other applications is limited by concerns over chipping and bond strength to the substrate.

Coating Properties

The physical properties of the sprayed coatings, including macro and microhardness, porosity, density, and bond strength are listed in Table 2. Cross sectional micrographs of representative coatings are shown in Figure 1. All show a very dense and oxide free structure, of much better quality than that which is typical for the sprayed plasma and flame spray coatings. Measurements of the adhesive bond strength in the as- sprayed condition for the coatings was performed in accordance with the test procedure described in ASTM C633-76 "Test for Adhesive Strength of Flame Sprayed Coatings". This consists of roughening the surface of a 1.0 in diameter 410 stainless steel cylinder with 25/40 mesh aluminum oxide grit followed by depositing 0.015 in of each coating. Each sprayed deposit was then bonded to a noncoated cylinder using a high strength structural epoxy adhesive. The samples are then pulled and the breaking load is divided by sample area to give bond strength. Bond strength values were all in excess of 8,000 psi and the majority were in excess of 10,000 psi. All bond strength values above 10,000 psi were epoxy failures. It should be noted that these values are significantly better than those obtainable for similar coatings deposited using a conventional plasma process.

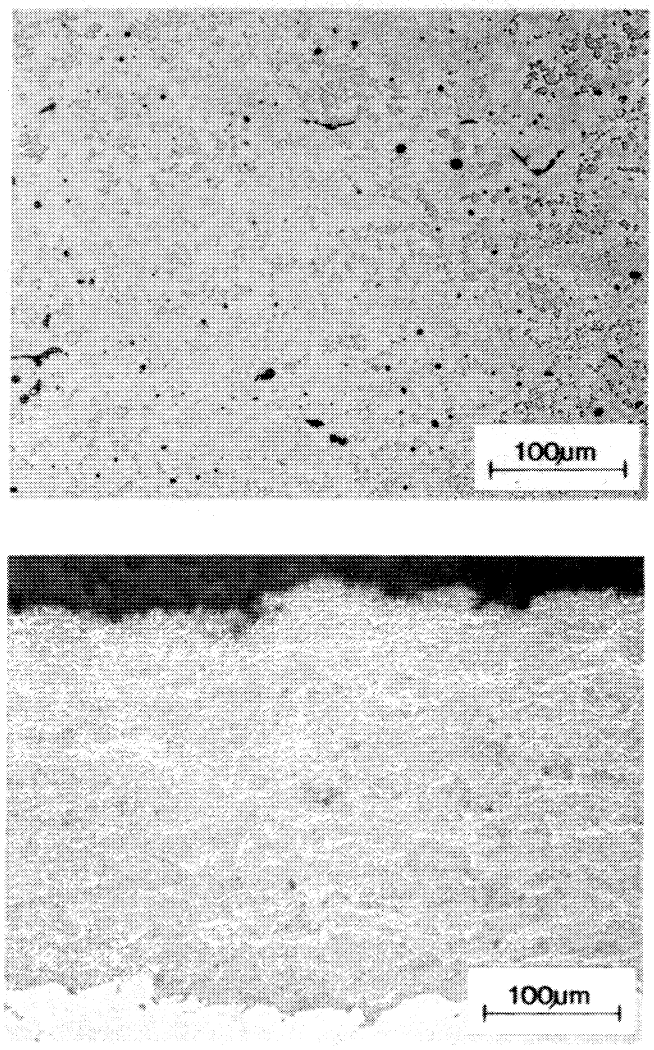
Abrasive Wear Resistance

The abrasive wear resistance was determined by subjecting each coated system to a low stress wear test. The test method consists of simultaneously abrading the subject coating and a known control in a slurry of alumina abrasive and distilled water. The slurry mixture consisted of 150 g of -53 µm + 15 µm aluminum oxide and 500 ml of distilled water. Samples were rotated at 235 rpm under a 200 g/cm^2 load. Thickness and weight loss were measured after each 10 minute run for a total of 20 minutes. The test was considered valid if the control sample wore at the same rate for each test, thereby allowing comparisons between different tests.

Results for the abrasive wear test are given in Figure 2. The tungsten carbide-cobalt coatings show consistently lower losses of both weight and thickness than nickel-chrome-boride and all other coatings. The tungsten carbide coatings exhibit increased resistance to abrasive wear as the tungsten carbide content increases. The ion-implantation coatings performed poorly, with the treated surface layer being breached in the first run.

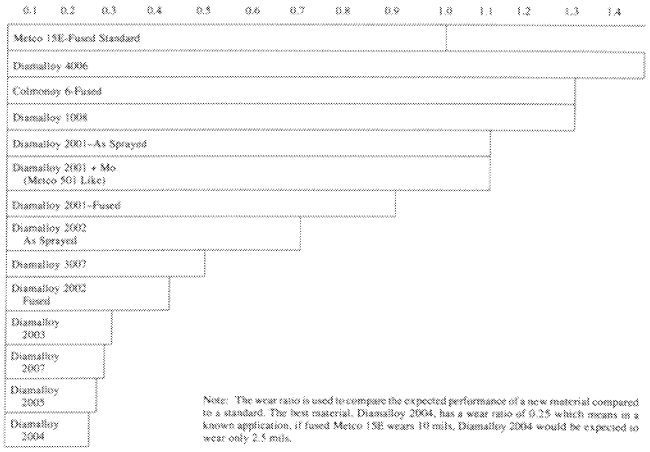
Particle Erosion Test

Room temperature particle erosion resistance was determined by the controlled impingement of aluminum oxide particles onto a coated plate. The impingement angles used for this study were 45 degrees and 90 degrees. The blast pressure was 60 psi and the



Diamalloy 2004-As Sprayed

Figure 1. Cross Sectional Micrographs, Showing Density of HVOF As-Sprayed Tungsten Carbide Coatings Similar to that of Fused Colmonoy 6.



Note: The wear ratio is used to compare the expected performance of a new material compared to a standard. The best material, Diamalloy 2004, has a wear ratio of 0.25 which means in a known application, if fused Metco 15E wears 10 mils, Diamalloy 2004 would be expected to wear only 2.5 mils.

Figure 2. Slurry Wear Test.

aluminum oxide grit was of an angular shape with a 53 µm to 15 µm size range. The coated panel was weighed before and after each five minute interval with total weight loss being recorded after 20 minutes. The impingement angle was varied between 45 and 90 degrees to study the different erosion mechanisms, where low angle of impingement (45 degrees) corresponds to a plow-shear wear mechanism and high angles (90 degrees) to a fracture wear mechanism.

Results of the particle erosion test are given in Figures 3 and 4. The results are consistent with those from the abrasive slurry test and indicate tungsten carbide-cobalt coatings deposited by the HVOF process were most resistant to abrasive and sliding wear conditions. Specifically, the 2004 formulation exhibited the highest degree of toughness as measured by the high angle impact erosion data, and outperformed the other coatings in both tests.

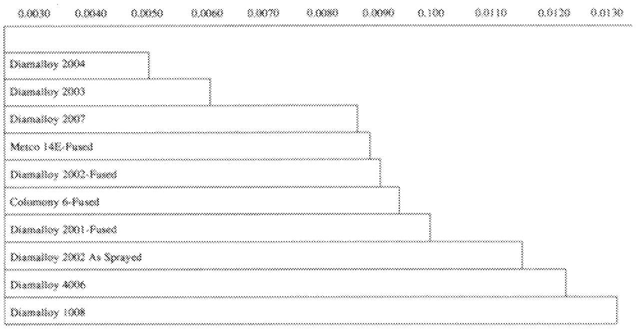


Figure 3. Blast Erosion—Volume Loss at 45 degrees.

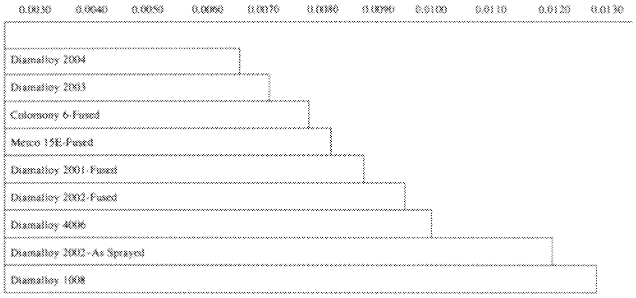


Figure 4. Blast Erosion—Volume Loss at 90 degrees.

Adhesive Wear Test

The adhesive wear test is considered critical to the total evaluation, because it is a standard, easily duplicated test. This test most closely simulates the relative motion and loading that can occur between rotating and stationary components, such as wear rings, in a pump. Also, the test provides two independent measures of resistance to adhesive wear. Both sliding wear and coefficient of sliding friction were determined by means of the ring-on-block test method described in ASTM G77. The test was conducted using an LFW-1 friction and wear testing machine. Each coating was applied to a type 410 martensitic stainless steel block hardened to 270 BHN maximum. Coating thickness were held to 0.010 in. Sliding wear was induced by contacting a rotating type 420 stainless steel ring, hardened to 450 BHN minimum, under load against the stationary block. Block and ring materials were specifically chosen to match those normally used in boiler feed pumps. Two tests were conducted. The load was set at 10 lb for test 1 and 20 lb for test 2. Weight loss of the coated block and uncoated ring was measured after each test. The test was conducted in tap water.

Adhesive wear test results are given in Tables 3 and 4. Under a 10 lb load, metal filled graphite exhibited the lowest coefficient of friction but largest scar width. This is consistent with material performance in service where it is known to be exceedingly resistant to galling, even under temporary dry running conditions, but relatively soft and therefore not resistant to abrasive wear. Under a 20 lb load, two coatings, fused Colmonoy 6 and Diamalloy 2004, exhibited lower coefficient of friction than metal filled graphite. These results were unexpected, and indicate that under severe galling conditions Colmonoy 6 and Diamalloy 2004 may be equivalent to metal filled graphite. None of the coated blocks shows any evidence of peeling or loss of adhesion to the substrate at the conclusion of this test.

An indication of good adhesive wear performance is low values for the coefficient of sliding friction, scar width, and ring weight loss. On the average, Diamalloy 2004 produced the best results. It is thought that the superior wear and erosion properties of this material are a result of the high volume percentage of tungsten carbide, the fine tungsten carbide grain size, and the greater toughness of the matrix phase indicated by its lower microhardness readings in comparison to the other tungsten carbide coatings.

Table 3. LFW Test Results at 10 LB Load.

Material	Method of Spray	Scar Width (Inches)	Coefficient of Friction		Wt. Change (g)	
			Avg.	Peak	Block	Ring
Metal filled graphite		0.0524	0.25	0.27	-0.0002	-0.0014
Colmonoy 6	SP-Fused	0.0369	0.26	0.30	-0.0008	-0.0005
2004	DJ-As Sprayed	0.0262	0.29	0.40	+0.0010	-0.0023
2001	DJ-Fused	0.0235	0.33	0.37	-0.0003	-0.0016
2001	DJ-As Sprayed	0.0352	0.35	0.40	-0.0004	-0.0016
Metco 15E	SP-Fused	0.0369	0.36	0.37	-0.0005	-0 .0010
2002	DJ-Fused	0.0139	0.38	0.44	-0.0008	-0.0021
3007	DJ-As Sprayed	0.0238	0.39	0.43	+0.0008	-0.0014
2005	DJ-As Sprayed	0.0205	0.41	0.46	+0.0001	-0.0017
2007	DJ-As Sprayed	0.0225	0.43	0.55	+0.0009	-0.0023
4006	DJ-As Sprayed	0.0291	0.46	0.54	+0.0016	-0.0027
2001 + Mo	DJ-As Sprayed	0.0258	0.47	0.54	+0.0007	-0.0028
2003	DJ-As Sprayed	0.0238	0.47	0.51	+0.0003	-0.0024
1008	DJ-As Sprayed	0.0443	0.52	0.57	+0.0003	-0.0021
2002	DJ-As Sprayed	0.0256	0.56	0.71	+0.0018	-0.0024

Table 4. LFW Test Results at 20 LB Load.

Material	Method of Spray	Load (lbs)	Scar Width (Inches)	Coefficient of Friction		Wt. Change (g)	
Colmonoy 6	SP-Fused	20	0.0500	0.23	0.44	-0.0010	-0.0022
2004	DJ-As Sprayed	20	0.0221	0.25	0.53	+0.0011	-0.0015
Metal Filled graphite		20	0.0861	0.26	0.28	-0.0038	0
2007	DJ-As Sprayed	20	0.0287	0.27	0.56	+0.0002	-0.0018
2001	DJ-Fused	20	0.0192	0.29	0.34	-0.0001	-0.0010
2001	DJ-As Sprayed	20	0.0352	0.31	0.34	-0.0004	-0.0016
Metco 15E	SP-Fused	20	0.0430	0.34	0.42	-0.0007	-0.0015
2002	DJ-Fused	20	0.0131	0.44	0.52	-0.0005	-0.0023
2002	DJ-As Sprayed	20	0.0287	0.46	0.53	+0.0007	-0.0034
3007	DJ-As Sprayed	20	0.0258	0.47	0.54	-0.0006	-0.0021
2005	DJ-As Sprayed	20	0.0229	0.48	0.56	+0.0009	-0.0023
2001 + Mo	DJ-As Sprayed	20	0.0299	0.48	0.58	0	-0.0028
2003	DJ-As Sprayed	20	0.0172	0.49	0.60	+0.0001	-0.0012
4006	DJ-As Sprayed	20	0.0365	0.52	0.57	+0.0012	-0.0024
1008	DJ-As Sprayed	20	0.0574	0.56	0.63	-0.0004	-0.0036

Analysis of Laboratory Data

Evaluation of all the test data indicates the 2004 tungsten carbide coating offers the best resistance to abrasive wear. For adhesive wear, the results are not as definitive because relative performance depends on the applied load. Colmonoy 6, metal filled graphite, and Diamalloy 2004 consistently show the lowest coefficient of friction. However, the much larger scar width for metal filled graphite indicates this material would deform or wear much quicker than the others. It is more fragile and less dimensionally stable under loading, implying more rapid loss of tolerances between rotating and stationary rings in a pump. This could mean loss in efficiency as leakage past the rings increases. Nevertheless, metal filled graphite has been successfully used in pumps handling both boiler feed water and low-specific-gravity liquids with poor lubricating qualities. There is also evidence [3] that it can withstand transient dry running conditions. It should be considered for these types of problem applications. Metal filled graphite would be rapidly damaged by abrasive particles, as indicated in these tests.

For applications demanding a measure of resistance to both abrasive and adhesive wear, as is often the case in pumps, Diamalloy 2004 appears to be the preferred choice based on the testing conducted in this program. This is an 88 percent tungsten carbide, 12 percent cobalt composition. Industrial experience with the 88-12 coating, primarily outside the pump industry, has been very good [4], with significant reductions in wear rates and few if any reports of coating bond failures. It would seem that the 88-12 composition is optimum for combined abrasive-adhesive wear resistance when run against a hardened martensitic stainless. While it was not evaluated in this program, there is published data [5] that concludes that tungsten carbide coatings cannot be used on both mating parts. Severe galling and coating failure is likely to result.

These findings are in full agreement with those of a recently concluded program [6] to evaluate coatings for improved resistance to seizure and galling in boiler feed pump internal seals. Similar coatings were tested in that study, also using an LFW-1 testing machine. Diffusion coatings were excluded because of concerns over thermal effects on base metal properties. The tests were conducted in water at room temperature. Coatings were applied to 410 stainless steel blocks and tested against a 410 stainless ring hardened to Rc 30. It was concluded that an HVOF tungsten carbide-cobalt coating gave the best performance based on weight loss, friction forces, and coating integrity when run against 410 stainless steel. Although not specifically identified in the published work, the tungsten-carbide coating is known to be Diamalloy 2003.

Field Exposures

Laboratory data must be confirmed by field exposure to establish a definitive comparison with existing materials. Selected applications have been chosen and HVOF tungsten carbide coated components (Diamalloy 2004 or equivalent) placed in service where exposure to severe abrasive or adhesive wear was anticipated.

A radially split double suction pump in service at a petroleum refinery suffered chronic wear due to an abrasive catalyst in the hydrocarbon product. The abrasive particles erode the casing (Figure 5), and internals, both of which had previously been repaired by welding. Coating the casing internal surfaces with stellite 6 increased life by a factor of about two to three to six months. Stellite was replaced with plasma applied tungsten carbide some three years ago, resulting in an increase in casing life to 12 to 14 months. The condition of casing and head, respectively, after this exposure are shown in Figures 6 and 7. More recently, HVOF Diamalloy 2004 has been used, resulting in an additional increase in life to 15 to 18 months. While this application illustrates the potential of high velocity tungsten carbide, it has been successful in part because the fluid does not contain corrosive sulfur compounds. Chrome carbide coatings with a nickel-chrome rather than cobalt binder are known to give better performance when sulfur compounds are present.

There are also reports in the literature of dramatic improvements in life obtained by the substitution of 88-12 tungsten carbide coatings for stellite. In one instance [7], involving abrasive wear in produced water injection pumps, life was extended from 600 to 5500 hours. A design change was also made and it is difficult to assess the relative contribution of each improvement. Nevertheless, this example is of interest because it indicates tungsten carbide HVOF coatings are being used on pump wear parts in diverse applications with good success.

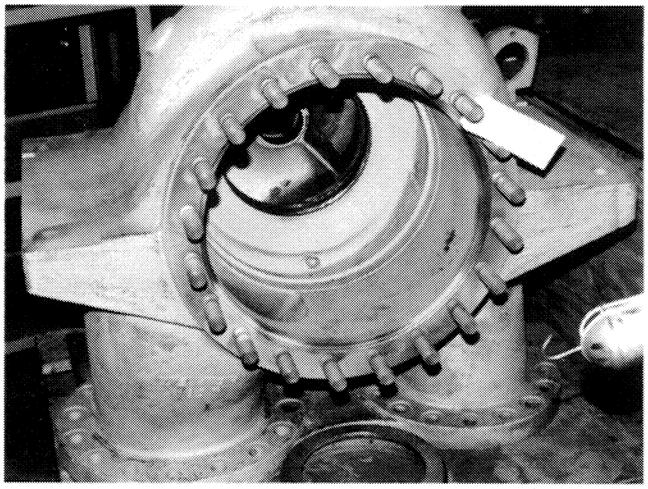


Figure 5. Pump Casing. Internal surface has been coated with plasma sprayed tungsten carbide and shows some wear after one year of service.

Figure 6. Closeup View Showing Wear of Plasma Applied Tungsten Carbide Coating in Pump Casing After One Year of Service.

Figure 7. Pump Head, Showing Failure of Plasma Applied Tungsten Carbide Coating After One Year Service.

In a second application, martensitic stainless shaft sleeves in a large multistage boiler feed pump were coated over a portion of their length with tungsten carbide. The pump operates at 5000 rpm and has had a history of hydraulic fluctuations, unsteady flow, and vibration. The tungsten carbide coated sleeves are the rotating component against a stationary 450 BHN breakdown bushing. After three months service, during which the pump experienced loss of suction on one occasion, and intermittent vibration, it was disassembled. The coated (dull gray) portion of the outboard shaft sleeve is shown in Figure 8 to be in excellent condition, whereas the shiny uncoated portion has suffered deep grooving from contact with the serrated breakdown bushing. Traces of grooving in the WC coating are less than 0.001 in thick. The inboard sleeve, shown in Figure 9 with the mating breakdown bushing, has galled in the uncoated area but shows minimal wear to the WC coating. Neither sleeve showed any evidence of coating to substrate failure in what must be considered a severe test of coating integrity.

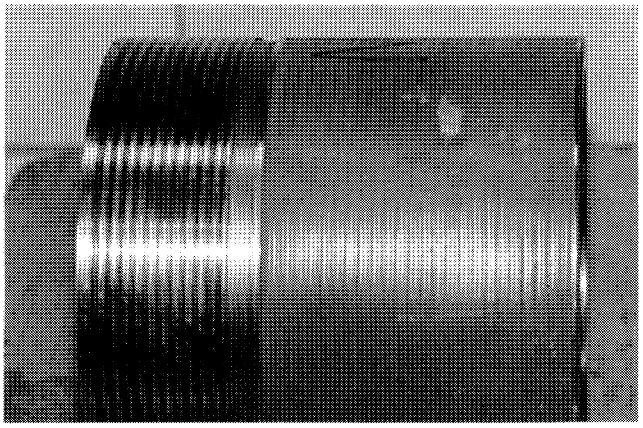


Figure 8. Outboard Shaft Sleeve from Multistage Boiler Feed Pump. Uncoated area, to the left, has been severely worn as a result of contact with serrated balancing device. Tungsten carbide coating shows little wear and no evidence of bond failure.

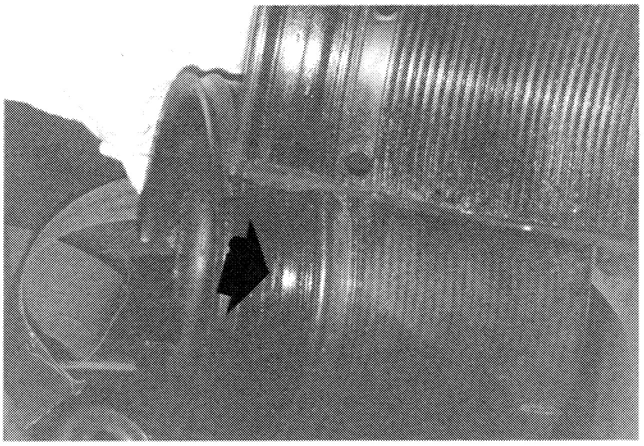


Figure 9. Inboard Sleeve has Galled in Uncoated Area (Arrow) Against Serrated Balancing Disc. Coated portion of sleeve shows only superficial wear and no evidence of galling.

While this represents the most demanding application in a boiler feed pump for which performance data is available, tungsten carbide coated wear components have also been used in boiler feed pumps in a variety of other applications, typically running against hardened martensitic stainless steel. Some of these applications, which comprise four different pump designs, have been in service for over one year, with no reports of coating failure. In one instance, a pump designed for boiler feed has been modified for descaling service. Tungsten carbide stationary wear components are successfully operating against nitrided martensitic stainless impeller hubs.

Tungsten carbide applied by the HVOF process used herein has also been used on the wear rings in large centrifugal pumps handling municipal sewage. In one application, excessive grit caused rapid abrasive wear to the standard rings supplied in martensitic stainless steel hardened to 400 Brinell minimum. Clearances opened to the extent of ½ in in three years. Specifications were upgraded to require 600 BHN minimum. Tungsten carbide coated rings were supplied and have been placed in service. Initial reports indicate the pumps are performing well. It should be noted tungsten carbide can be used on both stationary and rotating surfaces in this instance because these large slow running pumps have relatively generous clearances and the possibility for galling is remote. Similar pumps, installed in a large city on the East coast, have, for many years, used tungsten carbide coated wear rings without galling problems.

CONCLUSIONS

- The results of the laboratory tests indicate the following:
- Tungsten carbide coatings containing 88 percent WC in a cobalt binder offer the greatest resistance to abrasive wear of all coatings tested.
- The 88 percent WC coating also offers the best combination of resistance to abrasive and adhesive wear when running against hardened 410 stainless steel in a test intended to simulate rotating and stationary wear rings in a boiler feed pump. No bond failures occurred in either the as-sprayed or fused conditions.
- Metal filled graphite coatings have the lowest coefficient of friction when running against 410 stainless steel at the low loads. They do show a large scar width and are best suited for poorly lubricated and/or dry running conditions. They are unsuitable under even mildly abrasive conditions.
- At higher loads, metal filled graphite no longer enjoys a distinct advantage in resistance to galling as measured by coefficient of friction. Colmonoy 6 and/or Diamalloy 2004 show equivalent performance.
- Ion implantation surface treatments failed rapidly in abrasive wear tests.
- The laboratory data has been confirmed by good performance of HVOF tungsten carbide coatings in a variety of demanding pump applications requiring superior resistance to abrasive wear, adhesive wear, or both.

REFERENCES

1. Mason, D.L., and Rao, K., Second National Conference on Thermal Spray Characteristics and Applications of the Jet Kote11 Surfacing System.
2. Arata, Y., Ohmori, A., and Gofuku, E., "Studies on WC-Co System Coatings by High Energy Thermal Spraying," Proceedings of the 11th International Thermal Spraying Conference, p. 805, Montreal (1986).
3. Komin, R.P., "Improving Pump Reliability in Light Hydrocarbon and Condensate Service with Metal Filled Graphite Wear Parts," *Proceedings of the Seventh International Pump Users Symposium*, Turbomachinery Laboratory, Department of Mechanical Engineering, Texas A&M University, College Station, Texas (1990).

4. Kay, A., "Successful Hypersonic Spray Applications in the Steel Industry." *Thermal Spray Technology - New Ideas and Processes*, Editor D. Houck (1988).

5. Ludema, K.C., "Selecting Materials for Wear Resistance," International Conference on Wear of Materials, San Francisco (1981).

6. Luer, K.R., and Marder, A.R., "Wear Resistant Materials for Boiler Feed Pump Internal Seals," International Joint Power Generation Conference, Boston (1990).

7. Valantas, R.A., and Bolleter, U., "Solutions to Wear Related Rotordynamic Instability Problems on Prudhoe Bay Injection Pumps," *Proceedings of the Fifth International Pump Users Symposium*, Turbomachinery Laboratory, Department of Mechanical Engineering, Texas A&M University, College Station, Texas (1988).