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SURFACING ALLOYS

Technical Paper

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# Properties of Hard Surfacing Alloy Ni-15Cr-15W-3B-4Si-3.5Fe-0.6C (Colmonoy<sup>®</sup> 88)

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## Abstract

Colmonoy® 88 is a hard surfacing alloy designed to extend the life of OEM parts which are subject to various wear mechanisms in service. It can also be used to repair/rebuild worn parts subject to wear mechanisms and significantly extend their service life.

This hard surfacing alloy can be applied by various methods including; Thermal Spray processes, such as Sprayweld™, Laser Cladding, PTA welding, GTAW, GMAW, and HVOF. This paper will compare the properties of this alloy applied by different methods using various test procedures and the relative cost to benefit associated therein.

## Introduction

Thermal spraying dates back to the early 1900's. Arc welding processes date back to the early 1800's. Earlier metal joining processes (soldering and welding) are not relevant to this study. Surfacing technologies/processes include: Plating; Dip, Barrier and Chemical Conversion Coatings; Thermal Spray; Chemical Vapor Deposition (CVD); Plasma-Enhanced Chemical Vapor Deposition (PECVD or PVD); and Diffusion Coatings<sup>1</sup>. The purpose of hard surfacing, in this context, is to improve the performance of a part in service and/or restore dimensions and usability of a part subject to wear. This study compares the abrasive wear resistance of Colmonoy® 88 applied by several processes suitable for the alloy's available forms.

These processes are:

1. Conventional thermal spraying of powder using oxygen and acetylene with Spraywelder™ System.
2. Laser cladding with powder.
3. Plasma Transferred Arc (PTA) welding with powder.
4. Weld surfacing using rod by the Gas Tungsten Arc Welding (GTAW) process.
5. Weld surfacing using cored wire by the Gas Metal Arc Welding (GMAW) process.
6. Thermal spraying of powder by the High Velocity Oxygen Fuel (HVOF) process.

Along with abrasion resistance some other physical properties of the coatings, cladding and/or weld deposits were measured and are reported here.

Test procedures used include Abrasion testing by ASTM G65, Vickers hardness by ASTM E-92, Rockwell hardness by ASTM E18 as well as metallographic examples of the test specimens. SEM was also used with EDS to measure iron content in some of the coatings/deposits.

The Standard Test Method for Measuring Abrasion using the Dry Sand/Rubber Wheel Apparatus (ASTM G65-16) was used to measure volume loss of the surfacing materials. Procedure A of the Method uses a 130 N (13.6 kg (30 lbs) ) force holding the test specimen against the rubber wheel for 6000-wheel revolutions. During this 30-minute period AFS 50/70 mesh test sand (150 x 425 µm) test sand feeds between the wheel and the specimen at ~350 g/min. A schematic of the test apparatus is shown in Figure 1.<sup>2,3</sup>

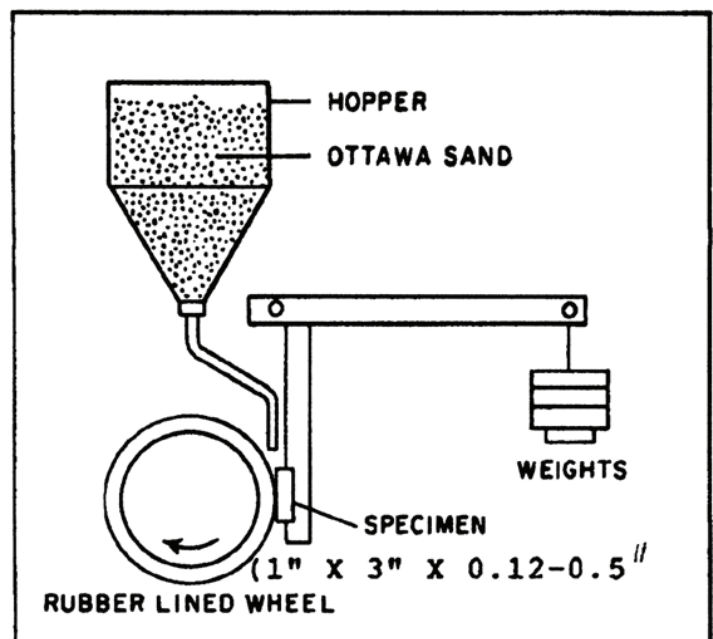


Figure 1. ASTM G65 apparatus

Coatings/Deposits of Colmonoy® 88 were applied to specimens of approximately 25 x 75mm and were prepared using each process under evaluation. Approximate deposition rates are shown in Figure 2.

Alloy Deposit Type	Approximate Deposition Rate (g/min)	Comments
Spraywelder™ System (Thermal Spray)	140	Spraywelder, Model J-3 Oxygen-Acetylene Fused Coating
PTA	25	Weld Tech 3500D Weld Overlay Two Layers
Laser	25	Laser Clad Overlay 1.2 kw @ 1000mm/min
GTAW (TIG) Rod	20	Weld Overlay, 1.5 kw Two Layers
GMAW (MIG) Wire	40	Weld Overlay, 8.5 kw Two Layers
HVOF	80	JP 5000 HVOF Coating Not Fused

Figure 2. Process summary

The compositions of the nickel-based alloy feed stock are shown in Figure 3. The elemental analyses fall with the normal ranges for Colmonoy® 88 alloy.

COLMONOY® 88		CR	W	C	Fe	B	Si
Deposit Type	Lots						
Spraywelder™ System (Thermal Spray)	92151-4	14.6	15.1	0.7	3.4	3.2	4.2
PTA	116823-0	14.9	15.4	0.7	3.6	3.0	4.1
Laser	116823-0	14.9	15.4	0.7	3.6	3.0	4.1
GTAW (TIG) Rod	115787	15.7	16.0	0.6	3.7	2.9	4.3
GMAW (MIG) Wire	115-6	14.4	17.3	0.9	3.6	2.8	3.7
HVOF	120135-0	15.1	15.3	0.7	3.4	3.0	4.0

Figure 3. Composition of Colmonoy® 88 lots

## Results

The Volume loss for ASTM G65 Procedure A are shown in Figure 4. The volume loss for the HVOF coating is considerably different from the balance of the application processes.

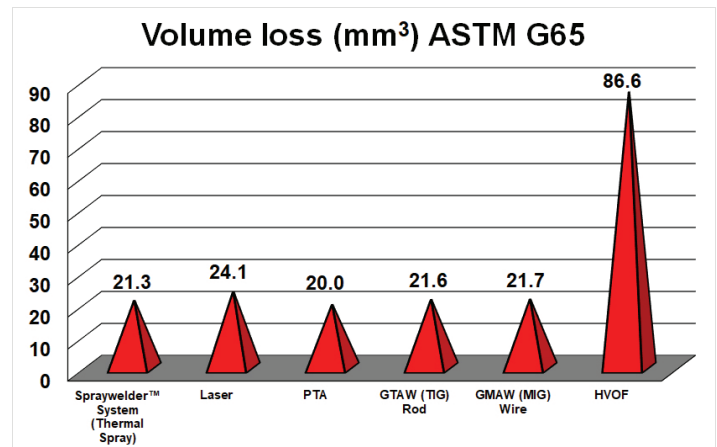


Figure 4. ASTM G65 wear test results

The average volume loss excluding the HVOF coating is  $21.7 \pm 1.5 \text{ mm}^3$ . The difference between the unfused HVOF coating and the fused/welded overlays will be addressed in the Discussion section. For reference; hardened D-2 tool steel is used as a standard for ASTM G65. Interlaboratory test results indicate a procedure A volume loss of  $35.6 \pm 5.2 \text{ mm}^3$ . The laboratory control test measured D-2 tool steel volume loss of  $35.3 \text{ mm}^3$ , which is within the expected standard range. Thus, validating this series of tests. Fused and welded overlays of Colmonoy® 88 exhibit lower volume loss than the D-2 tool steel standard reference material.

A summary of hardness testing is shown in Figure 5. This includes Rockwell C scale test, Vickers hardness with 500g load, and Vickers hardness with 25g load for hard phases large enough to support the test.

Alloy Deposit Type	Hardness Rockwell C Scale	Hardness Vickers 500g	Nominal Size of Hard Phases	Hardness Vickers 25g Nominal Hardness of Phases Present
Spraywelder™ System (Thermal Spray)	63	907	<40 μm	900-1375
PTA	64	868	<50 μm	950-1530
Laser	60	925	<20 μm	840-1340
GTAW (TIG) Rod	63	840	<65 μm	810-1360
GMAW (MIG) Wire	62	858	<100 μm	1000-1850
HVOF	58	715	<5 μm	n/a

Figure 5. Hardness results

The hardness test results shown in Figure 5 are actual values and not hardness conversions.

## Background

Colmonoy® 88 powder was developed in the 1980's (Reference US Patent No. 5,141,571). Since its inception the powder has been made available in the additional particle size distributions suitable for use in the thermal spray and welding processes used for this study. Additionally, rod and wire products were also developed. Five of the six processes used yielded the expected results.

It was expected that the microstructure of the overlays would correlate to the wear test volume loss. Metallographic examination does not lead to a direct correlation.

Figure 6 shows micrographs of the overlays by process. The specimens were etched with Marbles reagent to make the various phases/structures more easily visible.

Given the differing structures for the fused and welded overlays significant differences in ASTM G65 volume losses are not apparent. The expectation is that due to the test conditions and size of the abrasive sand, the test does not reflect results dependent on the size of the hard phases present. The grain size of the sand is approximately 3 times larger than the size of the hard phases present. One may expect to see different results if the abrasive were smaller than 50 or 25 microns.

The HVOF overlay underwent a significantly different thermal profile during application than did the others. Much of the microstructural characteristics remain similar to those found in the atomized powder feedstock. Since the degree of melting did not take place in the same time frame as the other processes the results indicate that the wear resistance of Colmonoy® 88 relies on precipitation of hard phases formed on heating near to or above the liquidus temperature of the alloy.

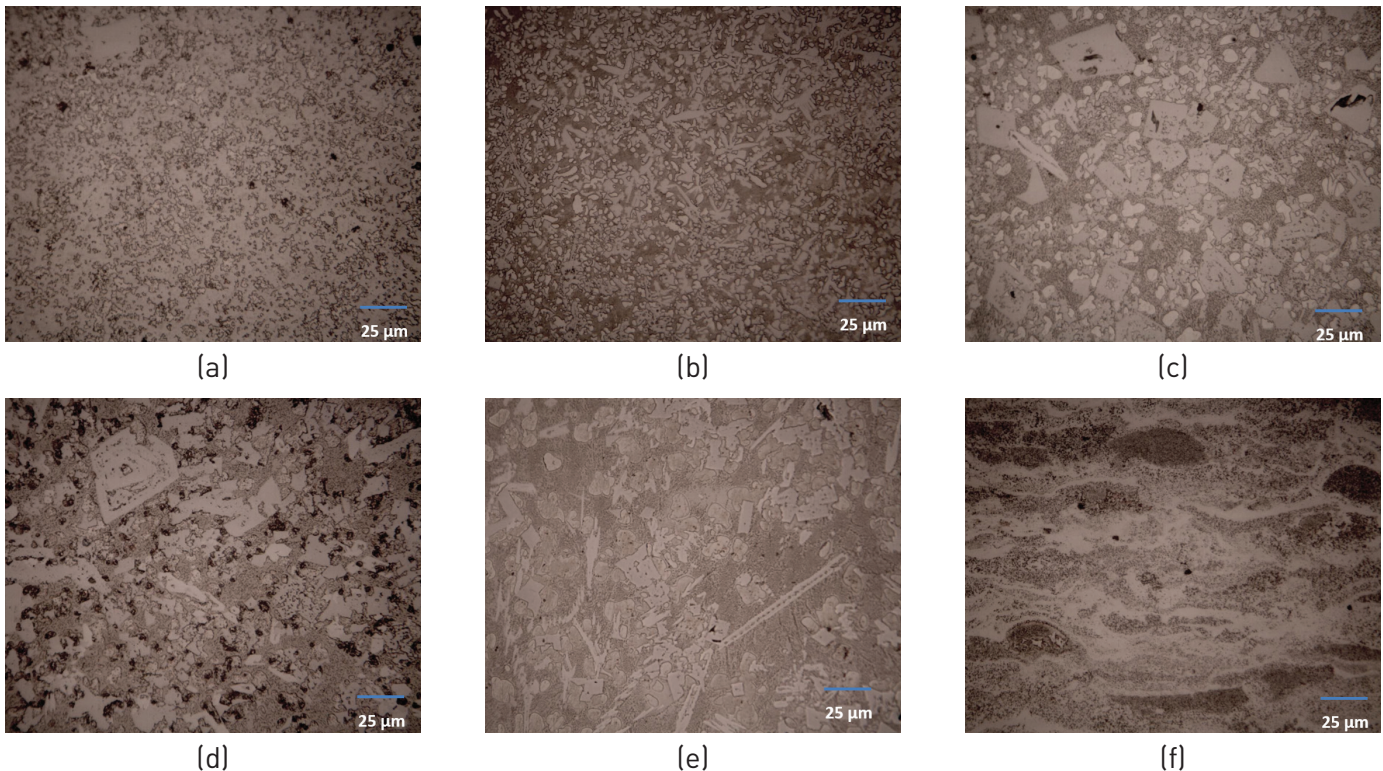


Figure 6. Micrographs of Spraywelder™ System (Thermal Spray) (a), Laser clad (b), PTA Weld (c), GTAW rod weld (d), GMAW wire weld (e), and HVOF (f)

Figure 7 shows a typical thermal analysis plot of heat flow versus temperature. This plot indicates phase changes including solidus/liquidus temperatures as well as phase formation on cooling during solidification.

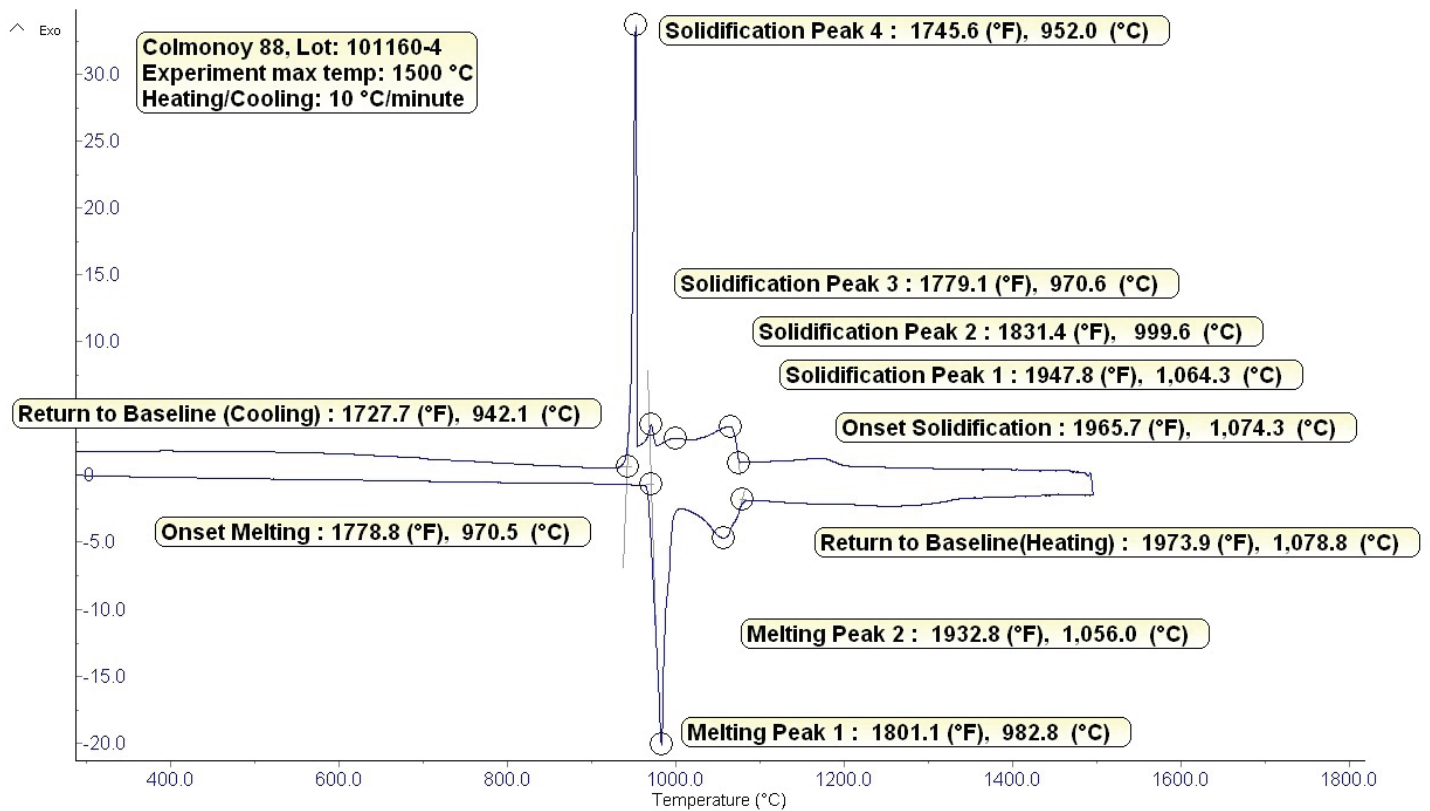


Figure 7. Thermal analysis trace by Differential Scanning Calorimetry (DSC) for Colmonoy® 88. Heating (bottom) and Cooling (top). Exothermic reactions peak upward, Endothermic reaction peak downward.

Although the wear test results (excluding HVOF) were not widely divergent we can see that temperature and time influence microstructure. Thus, it should be noted that sample preparation on small test specimens may not be representative of the process when the actual parts for service are made (ie. preheat & temperature & time factors). The specimens prepared for this study were all nominally 25mm wide x 75mm long x 19mm thick.

## Summary

Colmonoy® 88 when fused or welded, exhibits wear properties which are superior to hardened D-2 to steel under the G65 test conditions. The HVOF coating is nearly equivalent to normalized AISI 1090 steel under these conditions.

Under the ASTM G65 wear conditions the economics by process can be ranked based on the gas and electric and feedstock costs. Normalizing to the two-layer PTA weld overlay for a 1m<sup>2</sup> surface.

<b>Process</b>	<b>Approximate Cost Normalized to PTA Overlay to give same wear life (US\$/M<sup>2</sup>)</b>
Spraywelder™ System (Thermal Spray) - Fused	620
Laser (1 layer)	700
PTA (2 layer)	1170
GTAW (2 layer)	1360
GMAW (2 layer)	1940
HVOF	2690

## References

- [1] ASM Metals Handbook Vol. 5, Surface Engineering, published 1994.
- [2] American Society of Testing and Materials; Standard Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus; ASTM G65-16.
- [3] Evaluation of ASTM G65 Abrasive – Spanning 13 years of Sand; A. Doering, D. Danks, & M. J. Scott; Wear and Friction Resources, Houston Texas.

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