Roughening and Removal of Surface Contamination From Beryllium Using Negative Transferred-Arc Cleaning

R.G. Castro, K.J. Hollis and K.E. Elliott

Los Alamos National Laboratory
Materials Science and Technology Division
Los Alamos, New Mexico, 87545

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ABSTRACT

Negative transferred-arc (TA) cleaning has been used extensively in the aerospace industry to clean and prepare surfaces prior to plasma spraying of thermal barrier coatings. This non-line of sight process can improve the bond strength of plasma sprayed coatings to the substrate material by cleaning and macroscopically roughening the surface. A variation of this cleaning methodology is also used in gas tungsten arc (GTA) welding to cathodically clean the surfaces of aluminum and magnesium prior to welding. Investigations are currently being performed to quantify the degree in which the negative transferred-arc process can clean and roughen metal surfaces. Preliminary information will be reported on the influence of processing conditions on roughening and the removal of carbon and other contaminants from the surface of beryllium. Optical, spectral and electrical methods to quantify cleaning of the surface will also be discussed. Applications for this technology include chemical-free precision cleaning of beryllium components.

KEYWORDS: negative transferred-arc cleaning, beryllium, contamination

1.0 Introduction

Negative transferred-arc (TA) cleaning was developed by Mulberger et. al., in 1982 as a method for cleaning and preparing surfaces prior to the deposition of materials during low pressure plasma spraying [1]. The operation of TA cleaning results when a potential difference (voltage) is applied between the front of a DC plasma torch (anode) and the surface to be cleaned (cathode), Fig. 1a. A cathodic condition is created at the surface of the workpiece which results in the transfer of electrons from the workpiece to the front of the plasma torch during an electric-arc discharge. This electron transfer can cause the removal of the surface oxide and

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contaminates during the arc discharge. Pitting and localized melting can also result as the electric-arc attaches itself to the base metal. TA cleaning can improve the bond strength of plasma sprayed coatings as a result of this surface roughening [2,3]. A similar cleaning action occurs during gas tungsten arc (GTA) welding of aluminum and magnesium Fig. 1b.

Fig 1. a) Negative transferred-arc cleaning during plasma spraying. Front of the torch is (+) and the substrate is (-). Electron flow is from the substrate surface to the face of the plasma torch. b) Gas tungsten arc welding (GTA). Tungsten electrode is positive workpiece is negative. Electron flow from the workpiece to the electrode.

During GTA welding, if the tungsten electrode is positive and the workpiece is negative, electrons will flow from the workpiece to the welding electrode and ions will flow in the opposite direction. This configuration is typically used for welding aluminum and magnesium to remove the surface oxide during the welding process. A number of mechanisms have been proposed to

explain the oxide removal during GTA welding; 1) electron flow from the workpiece can break-up the oxide film on the surface, 2) bombardment of the surface by positively charged ions can also break-up the oxide film on the surface and 3) high electrical currents and resistance of the oxide can cause melting of the oxide [4].

A need currently exists in defense and magnetic fusion energy applications to quantify the degree of surface roughening and contamination removed from beryllium surfaces. A preliminary study on the TA cleaning of beryllium was performed by Castro et.al., [5]. Sputter deposited carbon was effectively removed from the surface of beryllium below the detection limit of the Rutherford Backscatter Analysis (RBS) (minimum detection limit $\leq 10^{13}$ atoms/cm²). Sputtered deposited tungsten was reduced by an order of magnitude from its initial surface concentration, Table 1. This preliminary study demonstrated that beryllium surfaces contaminated with carbon and tungsten could be effectively cleaned by the TA cleaning process.

Table 1. 1.6 MeV He RBS at centerpoint of Be tile samples. Measured elemental areal density (10¹⁵ atoms/cm²) [5].

Prior to negative transferred-arc cleaning					
ID	C	O	Ar	Cu	W
1	43.49	73.56	0.89	1.28	13.45
2	114.10	149.20	3.35	1.28	15.97
3	50.41	76.00	2.38	0.63	19.12
4	152.10	116.30	1.72	7.72	21.59
5	37.58	79.08	1.84	0.06	17.78
6	96.16	75.05	1.86	0.08	12.73
7	68.55	98.63	1.39	3.45	10.54
8	116.80	83.73	2.02	5.74	6.73
Following negative transferred-arc cleaning					
ID	C	O	Ar	Cu	W
1	n.d.	85.00	n.d.	u.d.	1.10
2	n.d.	65.00	n.d.	u.d.	0.68
3	n.d.	55.00	n.d.	u.d.	3.00
4	n.d.	93.00	n.d.	u.d.	0.41
5	n.d.	61.00	n.d.	u.d.	7.00
6	n.d.	43.00	n.d.	u.d.	9.60
7	n.d.	83.00	n.d.	u.d.	0.71
8	n.d.	120.00	n.d.	u.d.	1.30

n.d. = not detectable u.d. = present but undetermined quantity

A number of critical issues need to be investigated in order to consider TA cleaning a viable method for removing surface contaminants from beryllium:

- the degree of surface roughening,
- removal of specific types of contaminants (e.g. hydrocarbons, oxides, metals)
- methods for capturing contaminants removed from the surface,
- quantifying the degree of surface cleaning and
- monitoring and controlling the process

Operational parameters can substantially influence the removal efficiency and surface roughening that occurs during the TA process. Parameters which must be considered during the process are composition of the plasma torch gas, the torch to substrate distance, the substrate temperature, the power levels of both the plasma torch and the TA power supply and the chamber pressure. In this

study, chamber pressure was investigated to determine its influence on the surface roughening of beryllium. This research was performed at the Los Alamos National Laboratory's (LANL) Beryllium Atomization and Thermal Spray Facility.

2.0 Experimental

To investigate the effect of chamber pressure on the surface roughening of beryllium, samples (25.4 mm wide x 12.7 mm long x 3.2 mm thick) were TA cleaned at pressures of .004, .012 and .033 MPa. The standard operating parameters are given in Table 2. The surface of the beryllium samples were examined using optical and scanning electron microscopy before and after the TA cleaning process. The surface roughness was measured after TA cleaning using a Sheffield portable surface texture measuring instrument (Sheffield Measurement Division, P.O. Box 1127 Dayton, Ohio 45401-1127). Because of the toxicity issues associated with beryllium, care was taken to thoroughly clean the samples with acetone before and after TA cleaning to prevent the potential spread of beryllium contaminates.

Table 2. Standard operating parameters used for beryllium TA investigations

Parameters	Settings
Plasma torch	SG-100
Arc gas (Ar)	40 slm
Current (amps)	400
Voltage (volts)	25
Standoff distance (cm)	7.62
Substrate temperature (°C)	450
TA settings	
Current (amps)	150
Voltage (volts)	60
Pulser (on/off)	off

3.0 Results and Discussion

Figs. 2a, b and c are electron micrographs of the surfaces of beryllium after TA cleaning at .004, .012 and .033 MPa. Results of the surface roughness measurements are given in Table 3.

Table 3. Average surface roughness measurements.

Pressure (MPa)	Results (μm)
.004	5.5
.012	4.42
.033	1.75

Fig. 2. Negative transferred-arc cleaned surfaces of beryllium at various chamber pressures, a) .004 MPa, b) .012 MPa and c) .033 MPa.

A decrease in the surface roughness i.e., a more uniform and smaller surface roughness, was observed as the chamber pressure was increased from .004 to .033 MPa. Evidence of localized surface melting was present, to some extent, on all of the TA cleaned beryllium surfaces. During the TA process an electric-arc will momentarily attach itself to areas on the machined surface of beryllium. Localized surface melting can occur when the oxide on the surface of the beryllium provides enough resistance to electron flow that (I^2R) heating can occur causing melting of both the oxide and the underlying beryllium metal. Contaminates present on the surface of the oxide will also be removed during this arcing/melting process. The electric-arc phenomena and arc tracking that results from surface oxides has been extensively investigated by A.E. Guile [6,7].

Differences in the surface morphology of beryllium at the three different chamber pressures can be attributed to the rate of cleaning of the beryllium surface. The sample cleaned at the highest pressure (.033 MPa) exhibited smaller surface craters which is indicative of cathode arc attachment directly to surface contaminants such as oxides [7]. As the chamber pressure is reduced, the craters grow in size indicating a transition from arc attachment on a contaminated surface to arc attachment on a clean metal surface. At the lowest pressure (.004 MPa) the oxide was removed in addition to extensive arc attachment to the cleaned beryllium surface. Complete surface melting of beryllium can result during the TA process at low pressures and elevated substrate temperatures [3]. During the same time frame, at the higher chamber pressure, the arc attachment was only sufficient to selectively remove the beryllium oxide surface contamination. Since the samples are assumed to have the same amount of oxide on the surface, and all operating conditions were the same except for the operating pressure, the lower chamber pressure seems to promote a faster cleaning rate. A more constricted arc at higher pressures and higher energy losses to the gas in the conduction path between the plasma torch and the beryllium substrate may have contributed to the decreased cleaning rate observed.

Bond strengths between plasma sprayed beryllium coatings and beryllium surfaces, which have been roughened by TA cleaning, have been reported to be as high as 250 MPa [3]. The major contribution to the improved bond strength has been the mechanical interlocking that occurs between the beryllium coating and the rough beryllium surface. Surface pits present on the beryllium after TA cleaning act as sites where impacting molten beryllium particles can become entrapped during plasma spraying resulting in an interlocking between the coating and the beryllium surface. Evidence of mechanical interlocking between a beryllium plasma sprayed coating and a TA cleaned beryllium surface is seen in Fig.3. In this figure, part of a beryllium coating was trapped in a surface pore of the beryllium substrate. Upon testing of the beryllium coating/substrate interface fracture occurred in the entrapped beryllium coating. A metallurgical bond between the beryllium coating and the beryllium TA surface can also occur if the substrate temperature is high enough to promote diffusion between the interfaces [3].

Figure 3. Fracture surface of a beryllium coating entrapped in a surface pore of a TA cleaned beryllium surface.

4.0 Summary

Negative transferred-arc (TA) cleaning has been used effectively to clean carbon and tungsten contamination from the surface of beryllium and to provide varying degrees of surface roughening. At low pressures (.004 MPa) substantial roughening occurred on the surface of beryllium. For applications such as applying a plasma sprayed coating on beryllium, a rough surface can improve the adhesion of the coating by increasing the mechanical interlocking between the coating and the beryllium surface. For applications, such as chemical-free cleaning of precision beryllium components, an extremely rough surface would degrade the machined tolerance of the part. Understanding the fundamental issues which contribute to the TA cleaning process and the influence of processing parameters will be extremely important in developing this technology for precision chemical-free cleaning. To improve our understanding of the TA process a research program has been initiated at LANL to quantify the degree of contamination removal and surface roughening which occurs on beryllium during TA cleaning. A plasma spraying/cleaning system has been established which contains, spectral, optical imaging and electrical diagnostics to understand and control the TA process, Fig. 4. Laser plasma spectroscopy will be implemented into the cleaning chamber to perform in-situ analysis of the TA cleaned surface.

Figure 4. Schematic of plasma spraying/cleaning chamber at LANL used to investigate the TA cleaning process.

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