# Ion vapor-deposited Aluminum Coating inside the Hollow Tube

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Aluminum was coated by ion vapor deposition on the inner surface of hollow tube with inner diameter ranging from 6.5 to 22 mm with an aiming at extending the application of the technology. The process utilized the plasma as the intermediate medium in order to improve the adhesion and thickness uniformity. The coating structure was examined by SEM and X-ray, and showed (200) preferred orientation independent of applied bias voltage. The penetration depth increased linearly with tube diameter and elevated operating pressure. The effect of deposition parameters on microstructure and penetration depth of coating was mainly discussed.

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#### Introduction

Aluminum coatings by ion vapor deposition process of McDonnell Aircraft Company<sup>1</sup> has been successful as viable alternatives for cadmium electroplating in aircraft industry since 1974 among a number of available processes such as hot-dipping, calorizing, spraying, cladding, electroplating and others.<sup>2</sup>

The process is now recognized by military specifications<sup>3,4</sup> and it enabled to replace the cadmium-coated steel fastener in military aircraft with aluminum-coated steel fastener. The aluminum coating on aircraft components is currently used in a production scale<sup>5</sup> and becomes the baseline corrosion protection system for the US Navy F-18. The suitability of the innovative process to the automotive part was conducted in my lab and the IVD aluminum-coated bolt for exhaust manifolder was proved by in-service running test to show excellent corrosion- and oxidationresistant over the current electroplating.<sup>6</sup>

In recent years, the environmental issue has become one of the leading factors in eliminating the need for tank electroplating of hazard metals in the industry. Tighter legislation, which has been imposed to control the disposal of toxic wastes and reductions in the permissible level of hazard metals in the effluent, has effectively increased the cost of tank electroplating and made it less attractive.

IVD is an ion-assisted coating process which limits thickness uniformity in unfavorably compared with tank electroplating in internal recesses even though the technique is well established as cadmium replacement.<sup>7,8</sup>

To make the process useful in wider application, the applicability of its coating into hollow tube will be important. Therefore, we examine the validity of IVD aluminum coating in hollow tube application.

#### **Experimental**

Two kinds of specimens were prepared in this experiment. One kind of specimen were low carbon steel plates with 1.0 mm thickness and cut into 100X50 mm for structural investigation. The other were steel tubes with inner diameter ranging from 6.5 to 22.0 mm and cut to 300 mm in length

for penetration depth measurement. Prior to the coating, all the specimens were degreased in methyl-alcohol, washed and rinsed in deionized water, and finally dried in a hot air. The specimens were placed over the vapor source and hanged on electrically insulated cathode, which was negatively biased to 2000V in maximum. Plasma cleaning was carried out at bias of 600V for 20 minutes in the argon pressure of  $10^{-2}$  mbar. During the deposition of aluminum, the bias voltage was controlled below 1200V and the argon gas pressure were varied up to  $10^{-2}$  mbar for structural investigation of coating by SEM and X-ray, and for penetration depth by optical microscopy. The aluminum wire(>99.9%) of 0.6 mm in diameter was continuously evaporated in a feeding rate of 1.5 m/hr from the hot boat of boron nitride. The thickness of coating was measured with a calibrated micrometer equipped to an optical microscope after an ordinarily metallographical procedure. After IVD coating of aluminum. specimens were longitudinally sectioned for the determination of thickness profile. The penetration depth was defined as the distance from the tube hole entrance, 20.0 um to the point of one tenth of coating thickness, 2.0 um. The penetration depth was taken by averaging the five measurements for each specimen.

#### **Results and Discussion**

#### 1. Penetration depth through hollow tube

Figure 1 shows the pictures of aluminum coating coverage on the inner surfaces of hollow tube specimens of 6.5, 13.5, and 22.0 mm hole diameters treated under two kinds of operating pressure of  $6.0 \times 10^{-3}$  and  $1.5 \times 10^{-2}$  mbar.



Fig. 1 Pictures of aluminum coating coverage on various tube diameter and operating pressure.

(a)  $6.0 \times 10^{-3}$  mbar (b)  $1.5 \times 10^{-2}$  mbar

The coating thickness becomes thinner as the distance is further away from the hole entrance. The penetration depth measurements were tabulated with hole diameters in Table 1.

Table 1. Penetration depth with tube diameter.

Diameter Sample	$\phi = 6.5$	φ = 13.5	$\phi = 16.5$	$\phi = 22.0$	Remarks
А	2.1	6.1	-	14.2	6.0 × 10 <sup>~3</sup> mbar
В	5.2	9.3	-	22.1	1.5 × 10 −2 mbar
с	-	-	30.1	-	Vertical



Fig. 2 Relationship between penetration depth and tube diameter.

The penetration depth was observed to increase with hole diameter and operating pressure. Figure 2 demonstrates the linear relationship between the penetration depth and the hole diameter. As the operating pressure increased twice, the penetration depth increased twice as well. There will be 3 main factors affecting the penetration depth in this experimental work: scattering, line of sight, and electric field. Amongst 3 factors, coating thickness distribution in horizontal arrangement was controlled by scattering of the aluminum vapor atoms through their numerous collisions between the evaporation source and the substrate. The collisions were much enhanced by higher operating pressure and hole diameter as it contributed the penetration depth as evidenced in figure 2.

In case of vertical arrangement, the penetration depth was improved about 2 times as high as one

in horizontal at the same operating pressure. The line of sight was much effective in this situation rather than scattering.

# 2. Coating parameters on preferred orientation

Figure 3 shows the surface and cross-sectional morphology of aluminum deposited for 24 minutes at bias voltage of 1200V under the operating pressure of  $8 \times 10^{-3}$  mbar. The columnar crystallites were observed to grow on the substrate. The strongly oriented (200) deposit was found on X-ray diffraction pattern as shown in figure 4.



Fig. 3 Scanning electron micrographs of surface and cross section of aluminum deposit.



Fig. 4 X-ray diffraction pattern of aluminum deposit.

Table 2 and 3 indicated texture coefficient of aluminum at varied bias voltage and operating pressure. The texture coefficient of (200) increased from 2.46 to 2.67 as the bias voltage changed from 0 to 1200V. And it increases from 2.67 to 3.77 as the operating pressure decreases from  $1.7 \times 10^{-2}$  to  $8.5 \times 10^{-3}$  mbar. The value was strongly dependent on the operating pressure rather than the bias voltage.

Table 3. T.C. of IVD Al coating at different bias voltage

diffraction plane Bias Vtg(V,DC)	(111)	(200)	(220)	(311)
0	0.24	2.46	1.20	0.09
900	0.33	2.55	0.96	0.16
1,200	0.13	2.67	0.78	0.43

Table 4. T.C of IVD Al coating at different vacuum pressure.

diffraction plane (mbar)	(111)	(200)	(220)	(311)
$1.8 \times 10^{-2}$	0.13	2.67	0.78	0.43
$1.3 \times 10^{-2}$	0.27	3.59	0.07	0.07
$8.5 \times 10^{-3}$	0.11	3.77	0.07	0.05

### Conclusions

Ion vapor-deposited aluminum coating was conducted inside the hollow tube with an aims toward extending its application. The arrangement was crucial to get higher penetration depth. The vertical arrangement improves twice as higher penetration depth as horizontal arrangement. In horizontal, the penetration depth was linearly dependent on operating pressure and tube diameter.

The aluminum coating consists of columnar crystallites in (200) preferred orientation. Texture coefficient (200) increases slightly on bias voltage and strongly on operating pressure in reverse.

## References

- 1. D.E.Muehlberger, Plating and Surface Finishing, 70, 24(1983)
- 2. P.T.Stroupe & G.A.Purchy, Metal Progress., 57,59(1950)
- 3. Military Specification, MIL-C-83488
- 4. Military Standard, MIL-STD-1568

- 5. Seiji Machida, Jitsumu Hyomen Gijutsu, 31,11(1984)
- 6. Sik-Chol Kwon and et.al, Proc.3th Asian Surface Finishing Forum, p. 301(1989)
- B.T.Neivill, Plating and Surface Finishing, 86, 14(1999)
- 8. D.Lansky, Plating and Surface Finishing, 86, 20(1999)