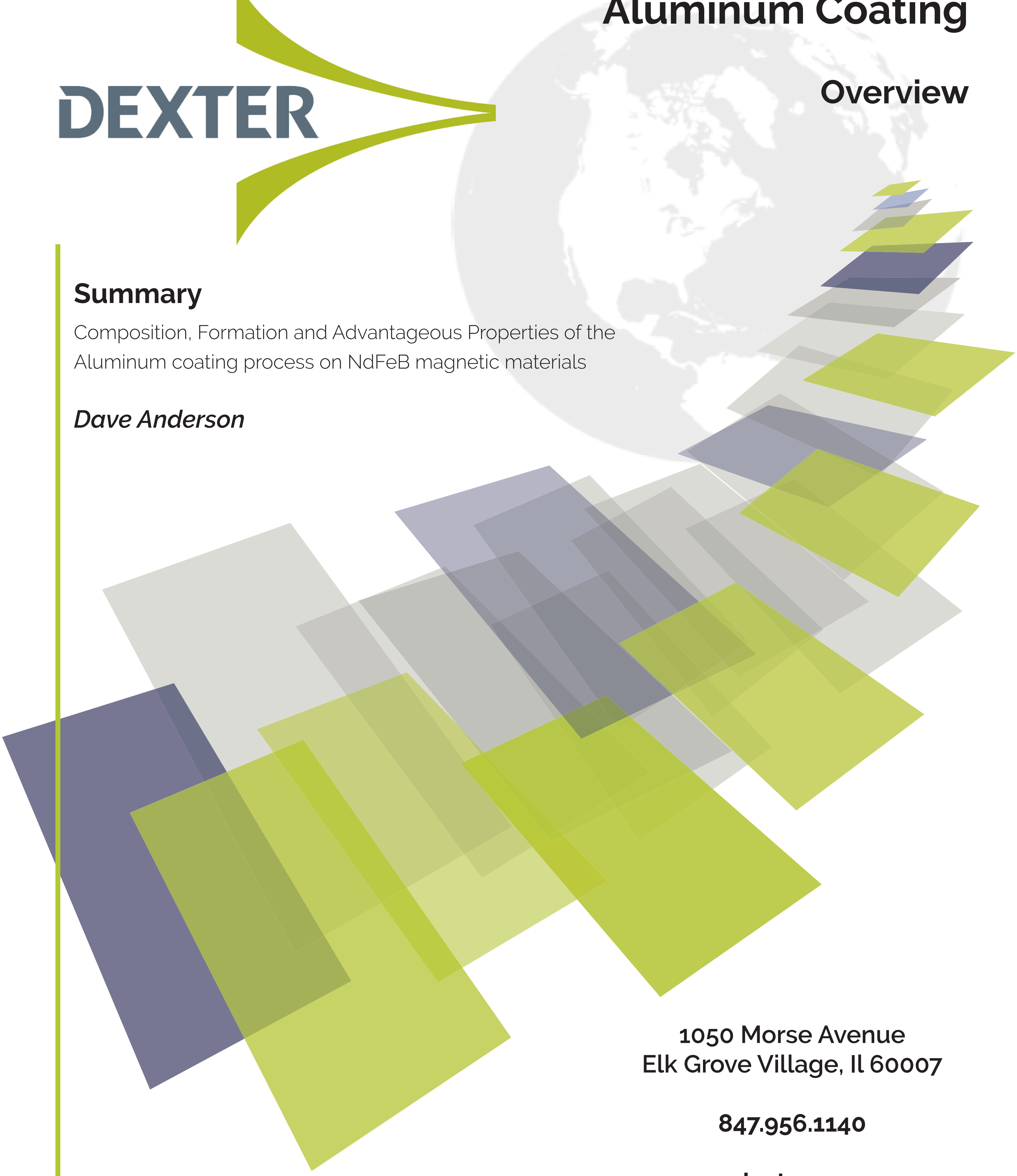
DEXTER

Aluminum Coating

Overview



Summary

Composition, Formation and Advantageous Properties of the Aluminum coating process on NdFeB magnetic materials

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Aluminum Coating
Composition

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The coating of substrates by ion vapor deposition (IVD) process results in a high purity coating of aluminum, typically >99.0% purity.[1] The aluminum is supplied typically as a wire that feeds continuously into the coating process. Commonly, the aluminum deposits in a columnar morphology because the energy of the gas phase aluminum ions is low, about 0.1 eV. However, subsequent processing and application of a chromate top-coat can be applied to help reduce the inherent porosity resulting from the columnar structure. Scanning electron microscope image labelled "(c)" in **Figure 1** illustrates the vertical morphology of the aluminum ion vapor deposited (IVD) coating on NdFeB surface prior to glass shot peening.[2] **Figure 2** shows a top view of the compacted surface following the glass shot peening.[3]

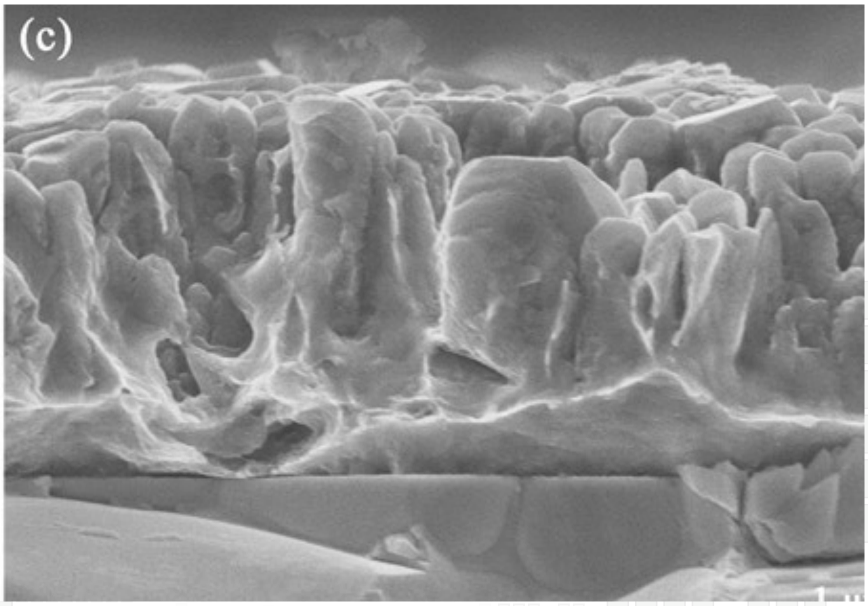


Figure 1. Columnar structure of aluminum on NdFeB surface prior to glass shot peening

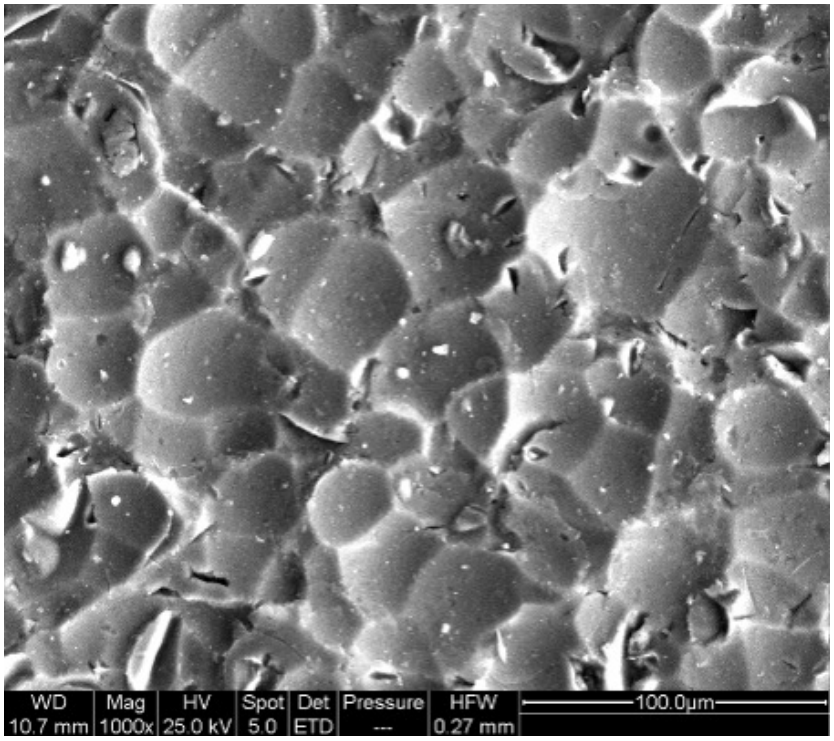


Figure 2. Compacted structure of aluminum on NdFeB surface after glass bead peening.

The first demonstration of ion vapor deposited aluminum was published in 1963.[4] Other processes for coating aluminum include cold metal spraying [5], cladding, evaporation[6], sputtering[7] chemical vapor deposition, and electro/electroless plating.[8] Cold metal spraying is limited to about 200 nanometer coating thickness, and cladding is limited by the mechanical form factor. Unlike the gas phase ion vapor deposition process, cladding cannot apply metals to very fine features. Electroplating and electroless plating both include the use of aqueous baths, and require exposing the substrate to water, which may be undesirable in some applications. Ion vapor deposition has the best “throwing power” (ability to get into small deep features, i.e. high aspect ratio) best thickness control, and best adhesion of common aluminum coating processes. Aluminum ion vapor deposition was commercially developed in the 1970s, initially as a substitute for cadmium (Cd), due to the toxic hazard associated with cadmium[9] as well as increasing regulation around the usage of cadmium [10]. Because the only by-product of aluminum IVD process is aluminum overspray, there is no toxic waste issue to address, because aluminum is non-toxic.

McDonnell Douglas led commercial development of the process and offered a system to execute the aluminum IVD process trade named “Ivadizer” in the 1970s. By 1996, there were over 70 Ivadizers installed worldwide.[11] It has been reported that the aluminum IVD coating is superior to cadmium in corrosion testing, including salt fog.[12]

The deposition of aluminum by ion vapor deposition includes the evaporation and ionization of elemental aluminum, followed by deposition on a cleaned, negatively charged substrate. Typically, the substrate is biased about 5kV to drive the positive aluminum ions to its surface. Also, the aluminum IVD coating can be applied in varying thicknesses across a single part. For example, in areas expected to undergo wear, thicker coatings may be applied, but in areas likely to be limited to chemical attack, a thinner coating may be required for dimensional control.[13] Similarly, parts may be masked for selective coating output. Like many other coating processes, surface preparation is also a key item for success.

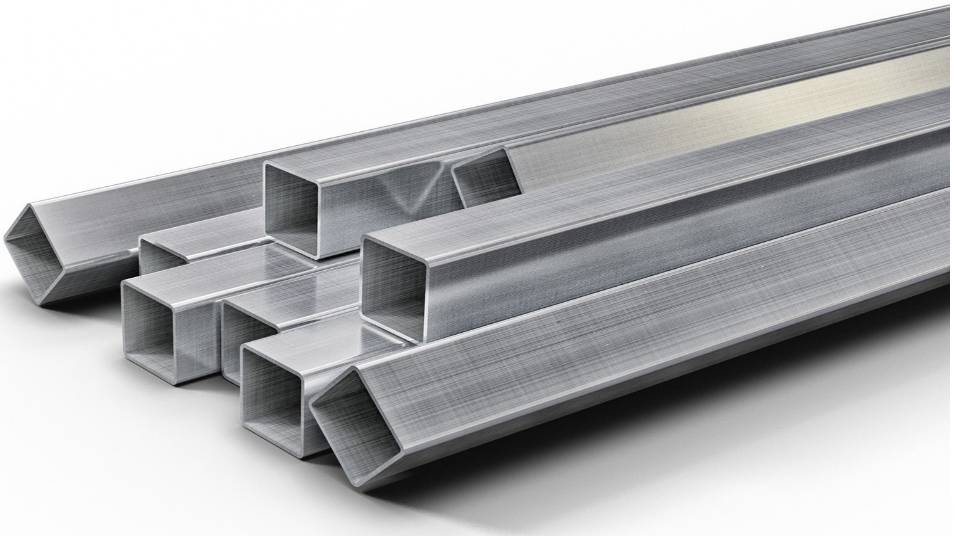
In the case of ion vapor deposited aluminum, the substrate is placed in a vacuum chamber and the pressure is lowered to about 10^{-5} torr, and then backfilled to 10^{-2} torr with Ar gas. A high voltage between the substrate and the aluminum results in an argon glow discharge which cleans the surface of the substrate to be coated. Following cleaning, aluminum is evaporated into the argon plasma, where it ionizes, and the positively charged, gas phase, aluminum ions are attracted to the negatively charged substrate, and subsequently deposit, resulting in the film of pure aluminum on the substrate. The thickness of the aluminum coating is controlled by metering the amount of gas phase aluminum provided to the argon plasma and ranges typically from 8-50 microns.

In addition, the fixturing of parts is nearly always an important issue to address to achieve success in a coating process. In the case of the aluminum IVD process, two important aspects should be considered. The fixture should be electrically isolated from the part itself so that the coating is limited to the intended part. Additionally, the fixture should be shielded from the evaporated aluminum so that it does not become conductive and short the potential applied to the part.

Aluminum Coating
Advantageous Properties

Because aluminum is relatively soft, it is less likely to be a source of crack initiation as a coating on substrates harder than itself. Therefore, it finds application on aerospace fatigue parts, where cracking failure is a common risk.[14] Aluminum IVD coatings are rated for continuous performance up to 925°F (500°C). The aluminum IVD coating process is gas phase, so, it is not "line-of-sight" limited. Gas phase atoms can diffuse through minute and complex 3-dimensional features. Where aspect ratio is defined as ratio of depth to diameter, holes with aspect ratio up to 2 can be coated with aluminum IVD. Aluminum IVD has been called the "best" protection against corrosion and climate loading as applied to NdFeB magnets, compared against sputtered, chemical vapor deposited, electrolytically, and electrolessly coated magnets, especially in acidic environments.[15]

Hydrogen embrittlement of metallic substrates is not a risk, because hydrogen is not included in the IVD process. Aluminum IVD can be applied to porous structures, including sintered metals, more conveniently than aqueous bath processes because fluids can be trapped within the porous structures following wet bath processing. Likewise, the use of aluminum IVD has been touted as "green" because of the lack of chemical byproducts or any additional material complexities.[16]



Aluminum Coating

Adhesion of IVD Aluminum to NdFeB Magnet Surface

The adhesion of the aluminum IVD coating to metals is generally considered to be excellent. Adhesive tensile strength is reported to be in the range of > 8000 PSI on magnesium, aluminum alloys and stainless steel.[17]

The mechanism of bonding derives from the energy of the collision between the gas phase aluminum ion and the substrate. Given that the substrate is negatively biased at 5kV, the positively charged aluminum ions are energized by the electromagnetic field and create a much stronger bond than that which results from ordinary vapor deposited metal.[18] This is a general mechanism that explains why better adhesion is observed for sputtered films compared to those formed by evaporation.

In sputtering, of which ion vapor deposition is one type, the gas phase coating material is energized by any of a number of mechanisms, and the collision between the gas phase atoms and the substrate is far more energetic than a neutral gaseous atom that diffuses to a substrate.gas phase coating material is energized by any of a number of mechanisms, and the collision between the gas phase atoms and the substrate is far more energetic than a neutral gaseous atom that diffuses to a substrate.

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