Thermal Sprays and Thin Films and their beneficial applications in the packaging industry

Nikki Cerrato
Packaging Science
University of Florida

Italian Packaging Technology Award-IPTA
September 2005-June 2006

Abstract

Metal coating technologies have been used in a limited number of industries over the past few decades, but their use in the packaging industry has not yet been fully implemented. Hard coatings, such as thin films and thermal sprays, could prove beneficial by improving wear resistance and durability of parts and tools, reducing maintenance costs for part malfunction and replacement, and increasing efficiency of packaging machinery. Several packaging applications have been assessed, however all areas of the industry can profit from new materials being tested and new application processes being researched. These new technologies have the potential to meet strict requirements and regulations, particularly those of the food and drug packaging industry. This paper discusses the historical background of hard coating technology, the application processes of these coatings, examples of tested applications, and the prospective use of hard coatings, such as thin films and thermal sprays, in a more widespread basis in the packaging industry.

Thermal sprays and thin films are well known for their applications in the automotive, aerospace, and biomedical industries. These coatings are applied to improve hardness, wear, and durability of machines and parts. Coatings are used to prevent corrosion and to increase the use life of machine parts. Many household products rely on coating technologies. The very popular Teflon® brand relies on thermal spray technology to create the pots and pans that are recognized for durability, non-stick properties, and cooking and baking benefits (8). Although there has been an increase in use of these coatings over the last few years, there are still industries that have yet to benefit from such advancements. Any industry that utilizes parts or products that experience extreme wear will profit from increases in strength and durability provided by the coatings.

Packaging lines can run five to seven days a week and anywhere from one to three shifts each day to meet production needs. Packaging machinery will last longer, experience improved runability and be more cost efficient with the help of thermal sprays and thin film coatings on metallic surfaces. Packaging machines are responsible for a variety of tasks including forming, trimming, filling, conveying, wrapping, sealing, and cutting (6). Simple packaging lines can easily produce hundreds of parts per minute. A packaging die or blade used for cutting film, foil or labels can cut thousands of parts in one hour! These production numbers increase the likelihood of wear and the need for maintenance or replacement of machine parts. The packaging industry is a perfect candidate for this improved metal coating technology.

Historical Background

Hard coatings date back to the early days of U.S. space research. The later models of the Mariner spacecraft, a family of nine spacecrafts launched to study Venus and Mars, were drastically improved with a dry film lubricant applied to extend wearlife of parts exposed to harsh environments and temperatures (1). Similar films found their way into the aerospace and defense industries. After extensive research on new materials and application processes, hard coating technology evolved into what is now recognized by many industries today. Industries such as aviation, transportation, industrial and consumer products have relied on the benefits of hard coating technology for more than 20 years (2). These industries are provided with improved wear, impact and fatigue resistance, increased hardness and durability, increased use life of parts, a decrease in costs related to maintenance and product loss and several other benefits linked with hard coatings technology. In recent years, several new coating materials have been tested, along with different methods of applying these coatings that may prove to be more cost effective in an endless list of applications.

Two hard coatings available and recognized by many industries today are thin films and thermal sprays. Thin films, typically between 2 and 5 microns, are applied for superior wear resistance, hardening, and friction reduction as well as release, slip, and non-stick properties (7). Thermal sprays, which provide a thicker coating between 3 and 7 mils, are linked with friction reduction, corrosion resistance, wear resistance, and longer tool life. A metal coating that is superior to the base metal is used to prevent peeling or flaking under production circumstances (6). All metallic coatings must be tested to evaluate performance requirements for preventing wear, abrasion, corrosion, and

chemical attack. These metal coatings provide superior performance to parts without having to use the expensive durable metals to build entire machines. An entire packaging machine built from Titanium Nitrate (TiN) would be very durable and perform well, but there would be no way to transport or move the heavy machine and absolutely no way to afford it. Instead, a TiN coating can be applied to critical parts in order to improve the machine performance at a reasonable price.

Table 1- Current Options for Metal Coatings (7)

High Performance	Teflon, PTFE, Nylon, Silverstone, Supra, Xylan, ETFE
Plasma Coat	Aluminum, Ceramic, Stainless Steel, Tungsten Carbide
Metals	Zr, Cr, Cu, Ti, Al, Ta, Mo, W
Carbides	WC, TiC, TaC, ZrC
Nitrates	TiZrN, CrN, TiAlN, TiN, ZrN, TaN
Carbonitrates	TiCN, TaCN, (Ti-Zr)CN
Multi-layers	Infinite combinations

Metal Coating Applications

Coatings are applied to parts using several different techniques including physical vapor deposition (PVD) or ion beam enhanced deposition (IBED) processes. The main difference between these two application processes is the temperature at which the metallic coating is applied. PVD processes require high temperatures reaching 538°C (1000°F), where the IBED process offers a low temperature alternative for the application of the same family of hard metal coatings, approximately 93°C (200°F) (3). Reaction chemistry and reactant delivery also differ between these two coating processes. The PVD reaction is thermally driven by high temperatures, while the IBED process relies on a reaction kinetically driven by kinetic energy of ions. During the PVD process, reactant metal surrounds the part in the form of a plasma cloud. The IBED process applies metallic coatings directly to the surface of the part (3).

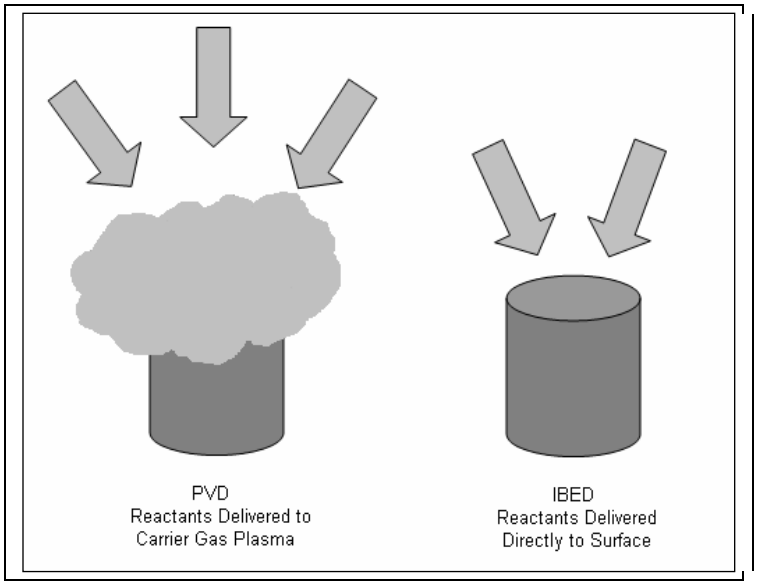

Figure 1- PVD versus IBED reactant delivery differences (4)

Although these coating applications are very different, results from a variety of performance tests have shown only slight superiority of the IBED process versus PVD. The IBED provided the coated parts with a smoother, more uniform distribution of particles (3). However, the two styles of coatings proved to be equivalent in areas including scratch resistance, adhesion tests, hardness, and wear rates.

Current Successes of Hard Coating Technology

Researchers at companies worldwide have been involved with many projects concerning the improvement of packaging machinery to improve output quality and plant efficiency. Studies and trials are being held to discuss the potential of metal coatings technology and how this technology can be implemented for food packaging and other packaging applications. After researching the benefits provided from the thin film and thermal spray coatings on metallic surfaces for other industries, this technology could potentially benefit these companies and their position in the packaging industry in the following ways:

- Increase the life of key tools and machine components exposed to corrosion, fatigue, stress, etc.
- Reduce production, maintenance and labor costs
- Improve functionality related to friction, release, wear, and hardness
- Improve sanitary conditions of operation

Several hurdles exist for the application of these high-tech coatings in the food packaging industry. Although a number of different coating materials exist on today's market, all coatings used by food and drug packaging companies would need to be approved by the Food and Drug Administration. Since all companies are responsible for meeting and exceeding all FDA standards, this may decrease the number of coatings that will be safe for applications in the food industry.

An in-depth assessment plan would need to be used in order to compare the performance of the coated tool or part to that of the uncoated part currently being used. This assessment will determine if the advanced coating application is sufficiently profitable. If the technology shows economic potential, a plan would need to be created for each project to determine which coating application is more appropriate for the part: thermal spray or thin film. In addition, companies would need to assess what tools can be replaced or coated, what the symptoms are if the tool or part is failing, and if a test or trial is feasible. With the research and testing provided from other industries, the following guidelines can be created in order to use the appropriate coating style that will be most beneficial for the assessed tool or part.

Thermal Sprays:	Thin Films:
Pumps	Cutting Tools
Blades	Dies
Rolls	Punches
Housings	Molds
Forming Heads	Rolls
Plows	Drills
Dough shaping/cutting tools	Slitting

Table 2- Suggested coating styles for different machine parts (7)

Metal coating applications were tested on machinery at several plant sites and multiple businesses were benefited from these metal coating trials. Below, a few examples of completed projects are provided to offer a better understanding of the real-life applications for the metal coating technology on packaging machinery. Several of the benefits that have been encountered, including cost savings and production efficiency, are clearly outlined in the project evaluations.

One hard coating success was accomplished when a plant faced the challenge of cutting knives wearing quickly on the production lines. The knives needed to be replaced every 7 to 10 days at four different plants. Each plant was experiencing downtime due to replacement of the knives and repeating proper calibration procedures. Maintenance costs included replacing the parts and the labor to replace them. A new knife insert was designed and built for these coating trials. The knife inserts were then coated with an enhanced thin film. The coating proved to increase the use life of the knife insert from 7-10 days to 3 months. After redesigning the knife assembly and applying the thin film coating, the total knife assembly was reduced from 70 days to one year. The changes in hardness and durability from the metal coatings reduced costs related to product loss, labor, maintenance and downtime (7).

At another hard coating trial, plants were faced with the problem of preventing wear on packaging plates due to metal to metal contact. This wear was leading to line downtime due to replacement of the plates. Maintenance costs for parts and labor increased, since the parts needed to be replaced every 8 weeks at an approximate cost of $5000 for each set of plates. The plates are an integral part of the production line since they are inspected by a United States Department of Agriculture (USDA) supervisor. Under the supervision of the USDA inspector, the part must be replaced any time the unit does not meet specifications. In order to improve functionality and increase the use life of the part, a two layer thin film coating was applied. A Titanium Nitrate (TiN) undercoating was applied directly to the plates with a Chromium Nitrate (CrN) overcoat. The Titanium Nitrate, which produces a gold metallic color, was used as a wear indictor when applied underneath the silver metallic layer of the Chromium Nitrate. After normal production and line procedures, the thin film coating increased life of plates from 8 weeks to about 6 months. The plates now have a useful life four times as long as the previously uncoated part. Since the plates no longer have to be replaced as often, downtime on the line and maintenance costs for parts and labor were reduced. Productivity and potential savings were significant after implementing the coated plates at two production sites (7).

An additional trial was held to improve the film overwrap forming tool. Plants were experiencing jamming of film in packaging lines. Jamming led to downtime every 15 minutes while the packaging line was stopped to remove film build-up on the overwrap plates. Maintenance costs increased due to replacement parts, labor, and sanitation efforts. Jamming was determined to be a result of high friction between the

overwrap plates and the film. In order to reduce film build-up, a plasma assisted thermal spray coating was applied. As a result of the coating, which provided a low coefficient of friction, jamming of the film on the packaging line was significantly reduced. There was no longer film build-up on overwrap plates, which reduced downtime and increased line capacity. Overall, the line efficiency has been improved and the production numbers have increased drastically (7).

Companies in the packaging industry have seen many positive results from use of metal coatings for a variety of applications across several types of business. Packaging engineers have seen improvements in functionality relating to friction, release, wear and hardness. Machine components that have been coated have had an increase in useful life related to corrosion, fatigue and stress. Non stick properties of metallic coatings have improved sanitary conditions, allowing for quicker and easier clean up at the end of each production shift. Overall, operation costs have been reduced at facilities that have implemented metal coating technology. Maintenance costs and downtime have decreased leading to an increase in operation efficiency (7).

Regulations and Challenges

Although there is an endless list of applications for metallic coatings in the packaging industry, food packaging companies may experience hurdles when searching for coatings that are United States Department of Agriculture (USDA) approved and Food and Drug Administration (FDA)-compliant. The food industry has strict guidelines that need to be followed, such as FDA, USDA, AgriCanada, and NSF codes, when food products come into contact with surfaces on packaging machinery. Contact surfaces of metal parts used in the food and drug industry must meet stringent requirements. The

surfaces must be dense and non-porous to prevent growth of mold and bacteria (5). Coatings must therefore be smooth and uniform across the entire part to avoid creating areas for bacteria to grow. This may prove to be an additional benefit of the IBED coating process which creates a smoother, more uniform coat. Research on additional applications processes that will create non-porous surfaces will be beneficial when meeting strict USDA and FDA codes. An additional regulation is in place that states that specialized surfaces impact the intended use of a part (5). For example blades must stay sharp despite the application of hard coatings. Coatings that come in contact with food processing machinery must not contaminate the food in any way (5). Metal coating manufacturers must work hard to meet the challenges of such rigid standards.

Hard Coating Potential in the Packaging Industry

In order to decrease the need for replacement parts, maintenance costs and product loss, problematic packaging lines should be examined to evaluate the possible need for new metal coatings. All machinery can be evaluated to explore the potential for use of thin films and thermal sprays in the packaging industry. If an opportunity is identified, tools and parts can easily be installed and tested to evaluate performance. At the packaging machinery manufacturing level, coating of critical parts and components before building new equipment may increase wear resistance of an entire production line. Coating parts of new packaging machinery may initially increase costs at the manufacturing level, but the resources spent on replacement parts and labor will decrease drastically due to the benefits of the hard coating. Machine manufacturers can work closely with hard coating suppliers to produce a new machine with all of the benefits of metallic sprays and films. Original tools and parts will perform better, last longer, and

part quality will be improved. Downtime will decrease as a result of an increase in use life of parts. Without wear, sticking, and fatigue of parts, production speeds will be faster than traditional packaging lines. Over time, the advantages of hard metal coatings will increase plant efficiency and corporate profits. Consumer satisfaction will increase as the price of packaged goods decreases as a result of decreasing manufacturing costs. Thin films and thermal sprays have the potential to greatly impact the packaging industry as a whole. Further research on metallic spray coatings and application processes, such as IBED and future advanced coating technologies, is therefore justified.

Table 3- Short List of US Companies that Provide Coating Services

Company	Website
General Magnaplate, Inc.	www.magnaplate.com
Impreglon	www.inpreglon.com
Ion Bond	www.ionbond.com
MicroSurface Corporation	www.microsurfacecorp.com
The Armoloy Corporation	www.armoloycorp.com
Alpha Metal Finishing Company	www.alphametal.com
Worthington BeamAlloy Corporation	www.worthingtonindustries.com/BeamAlloy
Vergason Technology, Inc.	www.vergason.com

Works Cited:

1. "NASA Reflections." Microsurface Corporation". <www.microsurfacecorp.com>

2. Ruggiero, Peter F. "Tungsten carbide coatings replace chromium." Advanced Materials and Processes. 163.7 July 2005: 39-40.

3. "Comparison of the Properties of PVD and IBED Hard Coats (TiN and Cr2N)." Worthington BeamAlloy Corporation. : 1-8.

4. Deutchman, Arnold H. Ph.D. and Partyka, Robert J. M.S. "Ion Beam Enhanced Deposition." Advanced Materials and Processes. July 2003: 33-35.

5. "FDA, USDA, AgriCanada, and NSF code compliant coatings on critical metal parts solve sanitation, maintenance, and performance problems on packaging and processing equipment." General Magnaplate, Inc.

6. "High-tech coatings enhance the efficiency and performance of packaging equipment." General Magnaplate, Inc.

7. Kinigakis, Panos and Plata, Maria. l. "Metal Coatings Applications for Food Processing Tools.": 2-16.

8. "Teflon Coatings for the Food Processing Industry." DuPont Teflon Industrial Coatings.