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# EVALUATION OF COMMERCIAL NONSTICK COATINGS FOR U.S. ARMY FIELD–FEEDING COOKWARE

by
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**14. ABSTRACT**

This report describes tests conducted on several commercial nonstick coatings for cookware. The tests include a qualitative portion and a quantitative portion to fully understand the nature and behavior of each coating. An effort was made to choose and test coatings that represented the full market for nonstick coatings. Given that there are literally thousands of variations on each type of coating, it is obvious that most coatings were left out of this test. It was the intention of the author therefore to balance variety with cost effectiveness so only one coating from each coating technology was selected. Coating samples were made and tested for material properties such as thickness, hardness, coefficient of friction, adhesion, wear resistance, corrosion resistance, thermal resistance and thermal shock. Army field cookware was coated with selected coatings and used to cook several meals. Observations were made as to the coating's condition during and after each meal. The general trend displayed in these two tests suggests that commercial coatings are not yet sufficient for use in an Army field-feeding scenario. However, more testing should be conducted on emerging technologies.

**15. SUBJECT TERMS**

| | | | |
|---|---|---|---|
| NONSTICK COATINGS | COMMERCIAL | HARDNESS | CORROSION RESISTANCE |
| QUALITATIVE ANALYSIS | FIELD FEEDING | WEAR RESISTANCE | THERMAL RESISTANCE |
| QUANTITATIVE ANALYSIS | MATERIAL PROPERTIES | ADHESION | THERMAL SHOCK |
| COOKWARE COATINGS | THICKNESS | COEFFICIENT OF FRICTION | TABER ABRASION |

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## 1. Preface

As the Army moves to a lighter, more mobile Objective Force structure, it becomes more important for equipment and materials to be lighter and easier to move. Water is one of the Army's largest logistic tails and field feeding sanitation operations typically use 250 gallons per day. The identification of an extremely durable nonstick coating for field cookware will help reduce the amount of water needed to clean army cookware therefore reducing the logistical burden on water for field feeding operations.

This report describes tests conducted on several commercial nonstick coatings for cookware. The tests sought to identify both quantitative and qualitative performance characteristics to fully understand the nature and behavior of each coating. An effort was made to choose and test coatings that represented the full spectrum of commercial nonstick coatings. There are literally thousands of coatings available and it is obvious that most coatings were left out of this test but the author grouped the coatings according to criteria such as material, deposition technology, base material, and cooking application and selected representatives of each, thus achieving a balance of variety and manageability in testing.

Sample aluminum coupons were coated with non-stick material and tested for properties such as thickness, hardness, coefficient of friction, adhesion, wear resistance, corrosion resistance, thermal resistance and thermal shock. Selected coatings were then applied to Army field cookware and used through several meals. Observations about the condition of the coating were made during and after each meal.

The tests were conducted at the Natick Soldier Systems Center in July 1999 for the Combat Feeding Program under Project Number AH99, Program Element Number 6227H6, Task Number C and Work Unit Number AF.

## 2. Acknowledgements

The author wishes to acknowledge the contributions and dedication of Don Pickard, Alex Schmidt, Frank Dileo and the members of the Equipment and Energy Technology Team (EET). Additionally, Ari Martin, and Katherine Sicard, students from Natick and Framingham, MA High Schools, respectively, provided immeasurable assistance as EET interns at the U.S. Army Soldier Center.

# EVALUATION OF COMMERCIAL NONSTICK COATINGS FOR U.S. ARMY FIELD–FEEDING COOKWARE

## 3. Introduction

Army field feeding is burdened by the cumbersome and slow process of sanitizing field cookware. Each day, hundreds of gallons of hot water and hundreds of pounds of equipment are used to clean and sanitize cookware. Heating the water heats and humidifies the tent as well, making the job difficult and unpleasant. Removing food stuck to pans is responsible for most of the energy, time, and effort required. The aluminum pots and pans that are used for field feeding are notorious for being hard to clean. Furthermore, when extremely charred food needs to be removed with steel wool, this removes the aluminum oxide coating from the pan and renders the cookware vulnerable to pitting and corrosion. The pitting makes future cleaning even more difficult or impossible. Pitted cookware is a haven for bacteria growth and over time the cookware becomes unusable and must be discarded.

The application of a nonstick coating to Army cookware would solve many problems. It would greatly reduce cleaning time and effort. Less water would be needed because most of the food waste could be wiped off the pan before introduction to the washing and sanitizing process, allowing the cleaning and sanitizing water to service more pans which translates to less greywater discharge, less energy used for heating the water, and also a better working environment. Lastly, by protecting the pans from corrosion, their life would be increased and food safety would be increased. The use of a nonstick coating would also protect the pan from corrosion and extend the life of the pan, as well as insure safety from food pathogens. Ultimately, nonstick coatings can pave the way for waterless sanitation techniques including sanitizing wipes. Cloth wipes impregnated with non-rinsing sanitizing detergents can be effective at sanitizing nonstick cookware that is wiped clean.

The largest problem with traditional nonstick coatings is their short life cycle. Scratching, flaking and peeling are all common to commercial and professional grade products. Great care must be taken to protect the coating from contact with metal utensils and abrasion of any kind. The addition of plastic utensils is unlikely, as they are known to melt. There is no guarantee that the rigors of field use will be kind to the coating; during desert operations, it is common for sand to find its way into every crevice of equipment.

A coating that will last in the field will have exceptional hardness and wear characteristics will be naturally non-stick Quality. Several products currently on the market claim hardness and wear resistance far exceeding that of typical cookware coatings. This study evaluates these novel coatings for their performance on cookware. Several technologies were researched including ceramics, polytetrafluroethylene (PTFE) impregnation of anodized surfaces. Typical commercial grade Teflon® or PTFE coatings were assumed inadequate for the rigors or Army field use however; the latest improvements on PTFE coatings were explored. Only viable commercial-off-the-shelf (COTS) solutions were pursued. The market research revealed a single company offering many coating options. General Magnaplate, Linden, N.J. offers a large menu of technologies, each with several formulations. Purchasing several coatings from a single company would save money and time, so three General Magnaplate coatings were selected for testing: a ceramic impregnated with PTFE and metals, a nickel coating impregnated with PTFE, a hard anodized coating and a hard anodized coating impregnated with PTFE.

Innovative Teflon® formulations were also explored. The commercial market for Teflon® -type polytetrafluoroethylene (PTFE) coatings has advanced rapidly in the past five years, increasing the options and technologies from which to choose. Several different manufacturing techniques have been implemented in attempts to optimize the hardness and wear properties of these coatings including the addition of binders, harder underlying layers. One notable approach is to embed stainless steel bits in the base metal to reinforce the PTFE and to divert metal utensils away from the soft coating. This type of coating was applied by Micro Surface, Morris, IL and tested.

Five coatings were selected for testing: Teflon®, hard anodized, a ceramic impregnated with PTFE and metals, a nickel coating impregnated with PTFE, and a hard anodized coating impregnated with PTFE. A bare aluminum surface was used as a control.

Quantitative coating performance was evaluated using American National Standard Institute (ANSI) material property tests. The properties of interest included: hardness, thickness, wear resistance, corrosion resistance, friction coefficient, and resistance to heat.

Qualitative testing included the repeated use during simulated Army field feeding exercises. Beef roasts and Swiss steaks were cooked in the pans repeatedly until the coatings began to show signs of wear.

Thus, the report is divided into two sections -- qualitative and quantitative. Each section contains its own test description, results and discussion. Overall results and discussion are combined at the end of the report.

## 4. <u>Quantitative Testing</u>

### 4.1. Coating Description

Five Army issued roasting pans made by Lincoln were coated with five different coatings. Three proprietary coatings from General Magnaplate were used, Tufram®, Plasmadize® and Nedox®. American Durafilm, Inc. applied a Teflon® coating. A hard-anodized coating was applied at Duralectra Co. The pans were then covered with masking tape and cut into 3” x 3” coupons using a high-pressure water jet precision saw.

#### 4.1.1. Hard Anodized

Hard anodizing is an electro-chemical process that converts the surface of raw aluminum to an artificial oxide coating. The process uses sulfuric acid as an electrolyte. When an electrical charge is applied, the hard anodize process is sustained on the surface of the aluminum. The coating is usually very thin and hard to remove because half of the coating is impregnated into the metal while the other half is on the surface.

#### 4.1.2. Teflon®

Teflon® is a DuPont brand name for a family of fluoropolymers consisting mainly of polytetrafluoroethylene (PTFE). Other fluoropolymer that are considered Teflon® are Dupont’s FEP, Tefzel® ETFE, and PFA. PTFE, the original resin, was introduced in 1946 with others to follow in 1960 and the early seventies. Teflon® is considered to be the slipperiest coating available on the market. In these tests, a Teflon® coating was applied by Microsurface Inc, and several coatings are impregnated with PTFE.

#### 4.1.3. Ceramic

Ceramic coatings are much more durable and wear resistant than PTFE coatings. They are also much thicker and applied in several layers. Intense heat is needed to cure them to the base metal and often a plasma spray is used in the application process. Because ceramic coatings sometimes lack good release properties, they are often impregnated with PTFE. Plasmadize®, the General Magnaplate coating used in this test, is a ceramic impregnated with metals for added hardness and PTFE for added release properties. It is Food and Drug Administration (FDA) approved for food processing applications.

#### 4.1.4. Metallic

Metallic coatings are generally very hard as they consist of a thin layer of a metallic substrate. They are applied in several ways, including electrolysis, vapor deposition or chemically. Nedox® by General Magnaplate is a nickel based coating evaluated in these tests. It is PTFE impregnated for enhanced release properties.

## 4.2. Test Methods

Seven parameters were sought for coating evaluation: hardness, wear resistance, corrosion resistance, thickness, friction coefficient, thermal resistance, and adhesion after thermal shock. All tests were conducted by IMR Test Labs, 131 Woodsedge Drive, Lansing Business & Technology Park, Lansing, NY 14882, P.O.# DAAN02-98-P-8652. Tables of results and pictures of samples were published in IMR report #1453.098. Each test was conducted according to, or based on, an ASTM standard test. A table of each of the ASTM standards can be found in Appendix A.

### 4.2.1. Thickness

Coating thickness is measured by viewing a cross-section of the material under a microscope according to ASTM B487-85. The thickness of a coating is important for several reasons. A thin coating may have excellent hardness and wear properties but may not endure because of the lack of material. Very thick coatings, however, can disturb the tolerances of a part. The thickness of a coating also affects its strength, what was originally plane strain can become complicated by plane stress. The thickness also determines the type of hardness test that must be performed; each test's indenter is rated for a different thickness.

### 4.2.2. Hardness

Knoop hardness is a method of measuring a material's hardness by its resistance to indentation. The method uses a precision diamond indenter and loads between 1 and 1000 grams force. The size of the impression is measured with a microscope according to ASTM E18-94 and ASTM B578-87.

### 4.2.3. Wear Resistance

Taber abrasion measures a material's resistance to wear by measuring the amount of material scraped off a flat surface subjected to an abrasive rotating disk. The disk is rotated for 1000 cycles under a 1000g weight according to ASTM B137-95 and IAW Fed-Std-141.1.

### 4.2.4. Coating Adhesion

This test evaluates the adhesion of a coating to its substrate (often the metallic pan surface). According to ASTM D3359-95a, a pressure-sensitive tape is applied over cuts made in the coating, and then removed at a 180° angle. The percentage of coating removed is reported. This test is typically used to test the adherence of a coating after it is subjected to other abusive tests as described below.

#### 4.2.5. Corrosion Resistance

Corrosion resistance is measured by subjecting the surface to a salt fog spray for 1000 hours (ASTM B117-97) The material is then examined for corrosion and subjected to a coating adhesion test according to ASTM D3359-95.

#### 4.2.6. Thermal Shock

Coatings are thermally shocked by cycling them from 500°F, down to 0°F and reheating to 500°F. This is repeated 5 times, holding the samples at each temperature for 20 to 30 minutes. The adhesion of the coating is then tested according to ASTM D3359-95.

#### 4.2.7. Thermal Resistance

The thermal resistance test determines the coating's ability to withstand moderately high temperatures for a sustained period of time. The coating is heated to 450°F - 500°F and held there for approximately 100 hours. The integrity of the coating is determined by a tape adhesion test ASTM D3359-95.

#### 4.2.8. Friction Coefficient

The coefficient of friction is a dimensionless parameter that determines how slippery a surface is. ASTM D1894-95 gives guidelines for determining both the static and kinetic friction coefficients. The force required to slide stainless steel across the coating is measured. General Magnaplate's coating friction data is shown in Table 1. While a low friction coefficient does not necessarily mean that a surface is nonstick because food can adhere to a surface at the microscopic level, rendering the friction coefficient unimportant, the friction coefficient is involved with non-stick on the macro level and can be an indicator as to the coating's non-stick properties.

**Table 1. Published Friction Data**

| | Static | Kinetic |
|---|---|---|
| Plasmadize® FT4 | 0.161 | 0.153 |
| Nedox® SF2 | 0.166 | 0.155 |
| Tufram® HO | 0.171 | 0.149 |
| Teflon® | 0.142 | 0.129 |

### 4.3. Results

Table 2 shows results that can be expressed numerically. Figure 1-Figure 5 are graphs showing these results for visual comparisons of the materials. Table 3 shows results from the more subjective yet rigorous tests such as salt spray and thermal resistance. Table 3 is supported by the photographs shown in Figure 6-Figure 11.

**Table 2. Measured Properties of Coatings**

| | Thickness (in x $10^3$) | Knoop Hardness | Taber Abrasion mg lost | Static Coefficient of friction | Kinetic Coefficient of friction |
|---|---|---|---|---|---|
| Aluminum Base Material | 0.00 | N/A | 24.5 | 0.27 | 0.20 |
| Anodized Coating | 1.42 | 430 | 1.8 | 0.29 | 0.19 |
| Nedox® Coating | 0.68 | 961 | 67.7 | 0.19 | 0.17 |
| Plasmadize® Coating | 2.68 | 14 | 43.1 | 0.20 | 0.20 |
| Teflon® Coating | 1.25 | too soft to measure | 14.5 | 0.22 | 0.17 |
| Tufram® Coating | 1.28 | 546 | 16.8 | 0.21 | 0.17 |

**Table 3. Results of Tape Adhesion Test**

| | Salt Spray Exposure** | Thermal Shock | Thermal Shock |
|---|---|---|---|
| Aluminum Base Material | Pass (extensive $AlO_2$) | No Damage to surface | No Damage to surface |
| Anodized Coating | Pass | Less than 5% removed | Less than 5% removed |
| Nedox® Coating | Pass (severe pitting) | Less than 5% removed | Less than 5% removed |
| Plasmadize® Coating | Pass (minor pitting) | Less than 5% removed | Less than 5% removed |
| Teflon® Coating | Pass (some pitting) | Less than 5% removed | Less than 5% removed |
| Tufram® Coating | Pass | Less than 5% removed | Less than 5% removed |

**See Figure 6-Figure 11 for photos

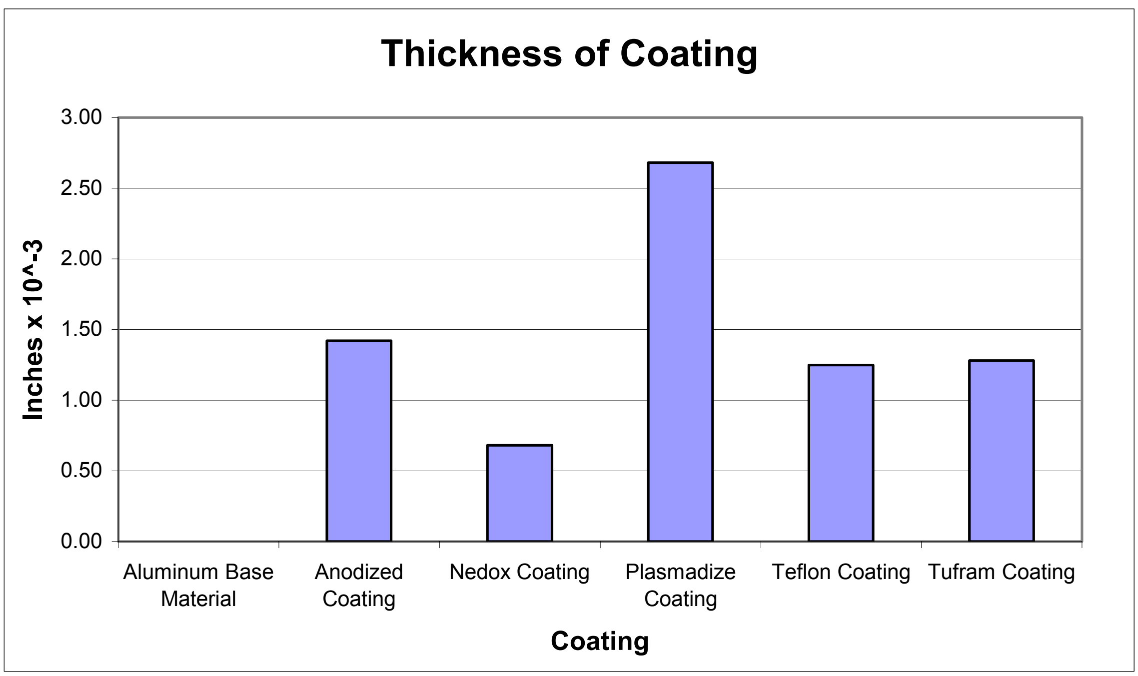


**Figure 1. Thickness of Coating Materials**

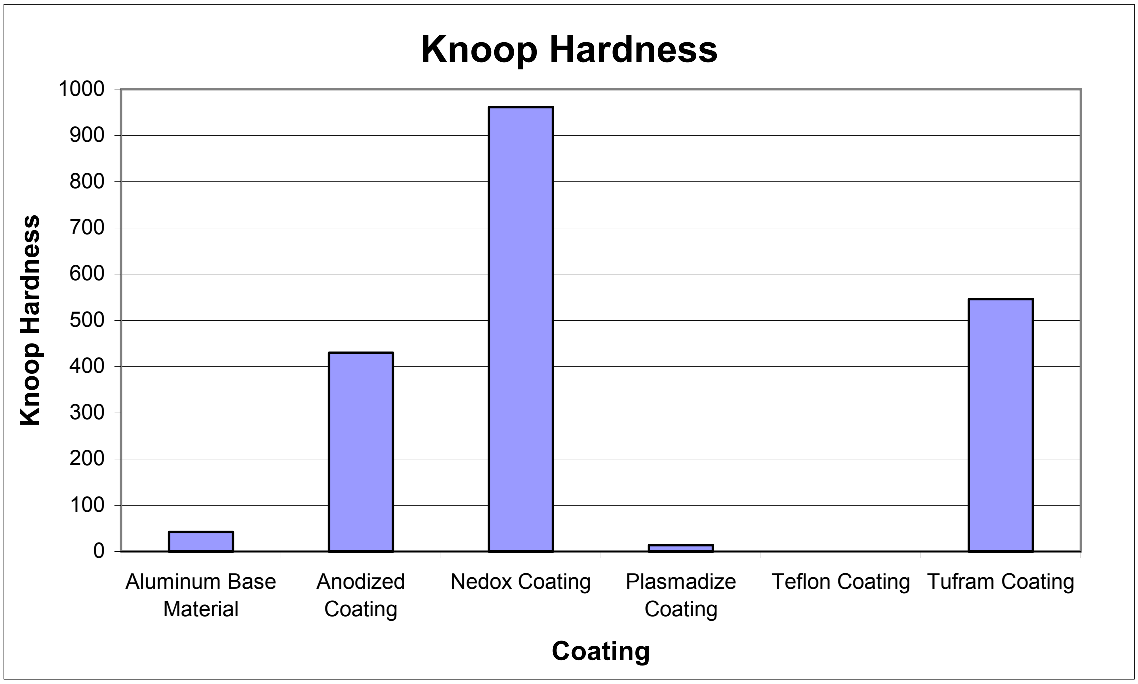


**Figure 2. Knoop Hardness**

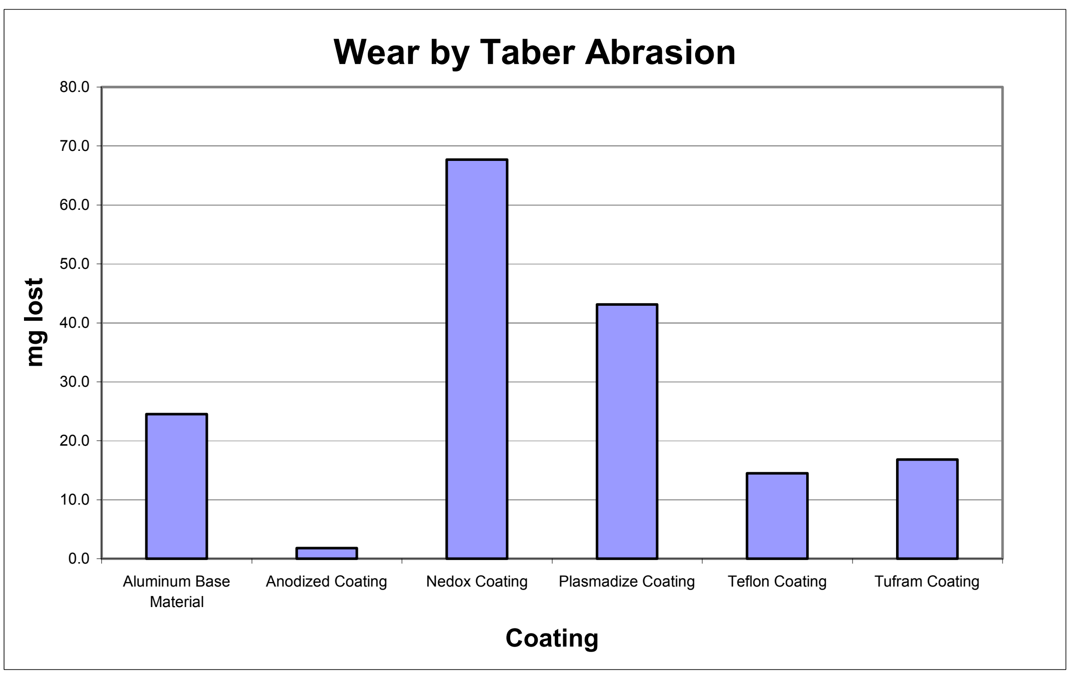


**Figure 3. Taber Abrasion**

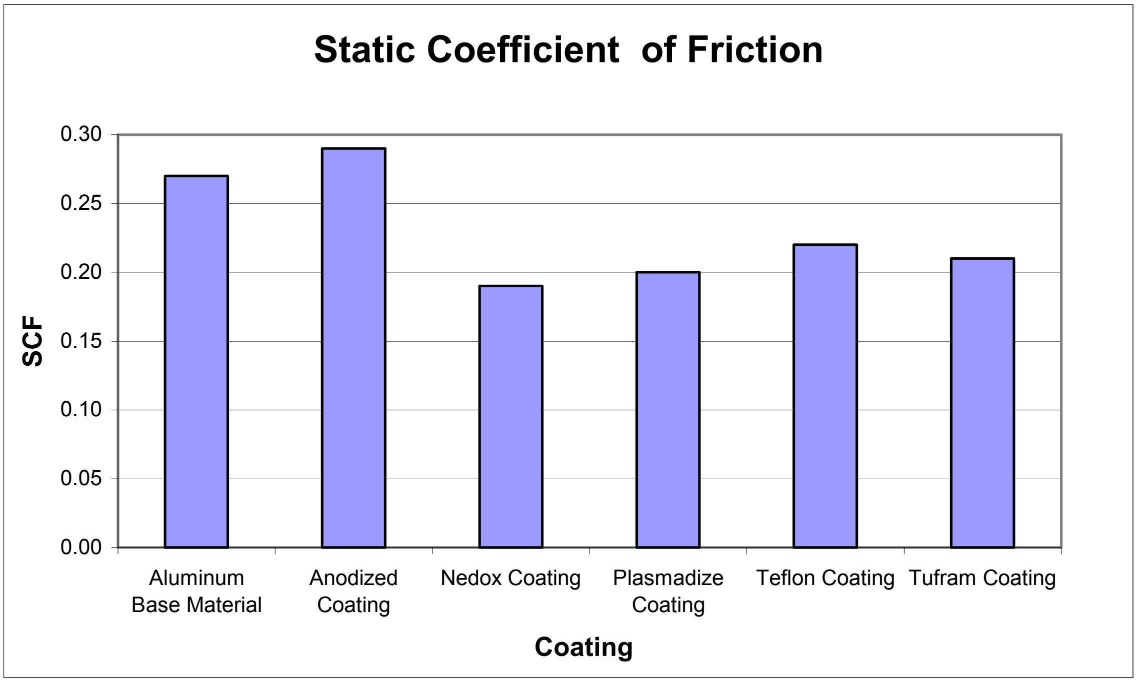


**Figure 4. Static COF**

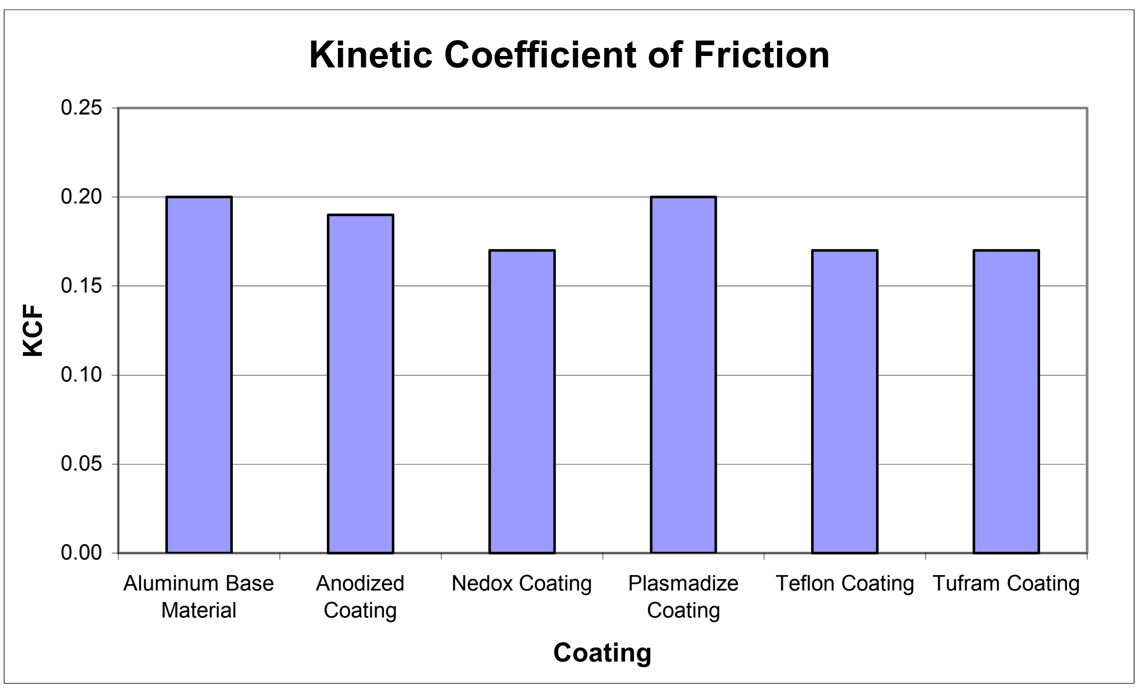


**Figure 5. Kinetic COF**

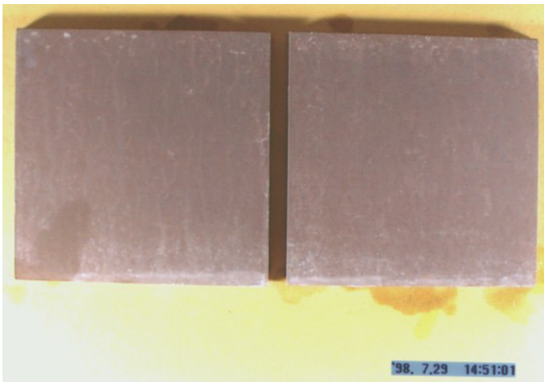


**Figure 6. Base Aluminum after Salt Spray**

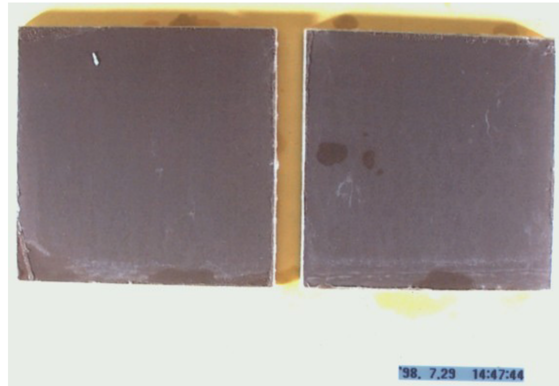


**Figure 7. Hard Anodized after Salt Spray**


**Figure 8. Plasmadize® after Salt Spray**

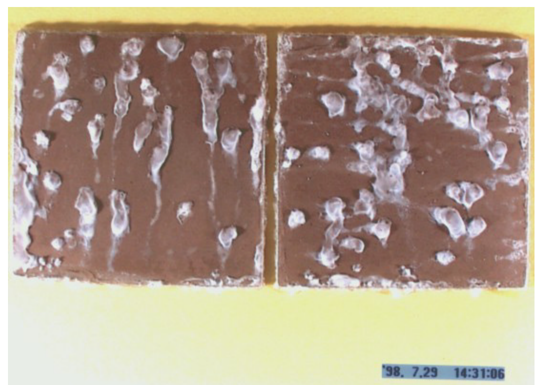


**Figure 9. Nedox® after Salt Spray**

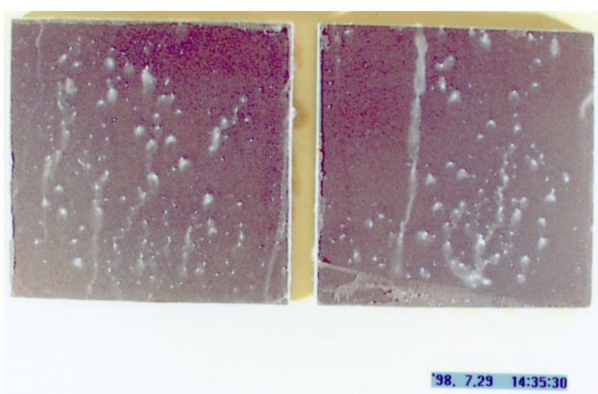


**Figure 10. Teflon® after Salt Spray**

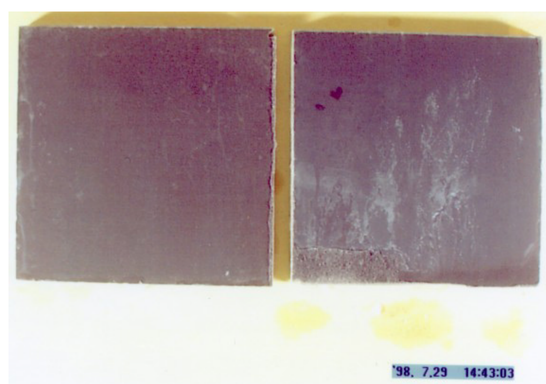


**Figure 11. Tufram® after Salt Spray**

### 4.4. Discussion

In this test, none of the experimental results reflected manufacturer's specifications exactly but did not seem biased; some properties tested higher than manufacturer's claims while others tested lower. It is possible some manufacturers tested their products using non-standard methods, or, that the number of samples tested was insufficient.

An ideal coating for large stockpots and roasting pans is one that releases food particles from the surface while remaining unscathed despite extreme conditions such as high heat and abrasion. That is, it will have low coefficients of friction, high hardness and low amounts of material lost in the Taber abrasion apparatus.

Though each test performed resulted in a very definite result, it is not straightforward to gauge which coating is best for all applications, particularly since a single coating did not excel in all categories. A coating will be very good in one area and therefore very bad in another. For example, Nedox® was extremely hard but did not do well in the wear test. Conversely, the anodized coating did well in the hardness and wear test but has a very high static coefficient of friction. The data is best interpreted by establishing tradeoff criteria for each performance category. While some areas might be rated very high, such as durability and friction, other's might be rated lower, such as thermal shock, and still others rated almost unimportant such as discoloration.

It was decided that corrosion resistance is the most important factor in the success of a coating in the field, because wear and tear experienced in the field will contribute to degradation of the aluminum over time. (In this study, the bare aluminum did not corrode as much as expected. Instead, an aluminum oxide layer was formed, protecting the aluminum underneath. But under actual field conditions, this oxide layer would be removed by scrubbing with steel wool after each meal, exposing the aluminum again to the elements.) Anecdotal evidence and data on the quantity of cookware procured each year shows that, indeed, bare aluminum pans have short lifespans in the field.

In these tests, only the two anodized coatings, appeared to resist corrosion altogether. The plain hard anodized coating and the Tufram® resist corrosion because they are more a surface treatment than a coating. In the anodizing process, a chemical reaction occurs between the aluminum and a chemical bath that changes the properties of a thin layer of aluminum at the surface to be extra hard. Their surfaces are very hard and non-porous. The Plasmadize® coating performed well overall in the tests. Even though it allowed come corrosion after 1000 hours of salt spray, its friction coefficients were on par with the Teflon® coating. It was, however, so thick that the coating interfered with the tolerances of the pan. This resulted in a lid that would not fit on the pan.

All other samples, including Teflon®, corroded noticeably. The Teflon® coating exhibits sites where salt migrated though the coating and began to corrode the base metal.

### 4.5. Conclusions

For these quantitative tests, the Tufram® coating was rated the highest for military application of all coatings tested. It had had the highest hardness, a reasonable abrasion loss and friction coefficients that rivaled Teflon®. At a Knoop hardness value of 546, Tufram® was 27% harder than the generic anodized coating and over 500% harder than the Teflon® coating which was too soft to measure. This is an indicator that Tufram® will be most resistant to sharp knife-edges and other metal utensils. Its friction properties were close to that of Teflon® indicating that the surface will release food as well. The material lost during abrasion was only 15% more than Teflon®, which is better than both the Plasmadize® and the Nedox® coatings.

## 5. <u>Qualitative Testing</u>

### 5.1. Introduction

In addition to comparing the coatings by their physical properties, it is also important to compare them in actual field-feeding scenarios. During qualitative testing two coatings were chosen based on the expected results of quantitative testing, (not available before qualitative testing began). Only two coatings were chosen because of the test complexity and limited cooking equipment. The two chosen were the Teflon® coating and the Plasmadize®. They were chosen based on PTFE's status as the industry standard's non-stick coating and the ceramic nature of the Plasmadize® coating that suggested that it would have excellent wear characteristics.

Army issue, heavy-duty roaster pans (squareheads) were used. Three meals were cooked on each of the pans over a Modern Burner Unit (MBU) in M59 range cabinets as would be done during Army field-feeding operations. The parameters observed included the amount and severity of stuck food and the effort needed to remove it.

### 5.2. Approach/Scope

These tests will were conducted on a Mean Time to Failure (MTTF) basis. That is meals were cooked using the sample pans until the coating fails as determined by the following criteria:

- Peeling of coating
- Flaking of coating
- Chipping of coating
- Staining
- Pitting
- Loss of "nonstick" property

When any of the above-mentioned criteria is met, the test will include one further meal to determine whether the problem is stable or worsening. The "time" variable is defined as number of meals until failure. A meal is defined as preparing food, cooking food, and cleaning and sanitizing pans.

### 5.3. Procedure

Two Army-issue roaster pans, each with different nonstick coating applied to them, were tested alongside an uncoated roaster pan as a control subject. Pan #1 was coated with the Plasmadize® FT4. Pan #2 was coated with a DuPont Teflon® coating by Durafilm Inc. Pan #3 was the control; and was a brand-new uncoated aluminum squarehead.

The pans were initially washed and sanitized using a commercial dishwasher. After each meal, they were washed manually using warm water, commercial dish soap and a green scrub pad. The cleaning operations were not timed, but subjective observations were made on the ease of cleaning. The same three pans were used for each meal. The pans were treated as they would during a standard field feeding exercise; standard Army issued metal utensils were used during each meal and care was not taken not to scratch the pans.

#### 5.3.1. Meal 1 – Roast Beef with Carrots and Onions

Two similar sized raw beef roasts were added to each of the three pans. The total weight of the beef ranged from 18-24 lbs. The roasts were rubbed with salt, pepper and garlic powder. Onions and carrots were chopped and added. The full pans were then placed on the top of the M59 range cabinet with the cover down and the MBU on low until the roasts were medium rare.

#### 5.3.2. Meal 2 – Swiss Steaks

Thin steaks were dipped in flour and fried on roaster covers then set aside. Tomato sauce was added to each of the pans and boiled. The fried steaks were then placed in the sauce and cooked for an hour. The steaks were then removed along with most of the sauce. A small amount of sauce was left to simmer for 20-25 minutes to congeal and/or burn and stick to the pans.

#### 5.3.3. Meal 3 – Chili Con Carne

Roaster pans were ¾ filled with canned chili con carne. The chili was brought to a boil and simmered for 2 hours. Most of the chili was served. A small amount was retained to burn and stick to the pans.

### 5.4. Results

#### 5.4.1. Photos

The procedures and results of each meal were documented by photograph. Figure 12 through Figure 39 are arranged in the following pages in grids. The first column shows the progression of the Plasmadize® coated pan from start to finish, the second column shows the Teflon® coated pan and the third column shows the uncoated pan. The top row shows the pan condition before cooking, the middle row shows the extent of damage from cooking and the bottom row shows the condition of the pans after a gentle rinse.

#### 5.4.2. Meal 1 Discussion

Figure 12-Figure 20 depict the results of Meal 1 with the pans starting brand new. Figure 15, Figure 16, and Figure 17 show the aftermath of cooking roasts. The Teflon® in Figure 16 had a handicap; the carrots and onions were added too early, so they ended up burning and becoming charred. The sugars became mixed with juices from the beef to form a layer of sticky carbon on the bottom of the pan. In other cases, such as the

Plasmadize® in Figure 15 this sugary mix had the effect of leaving the carbon layer covering almost the whole bottom of the pan with the exception of where the roasts had been. After cooking was complete, each pan was pre-washed by adding water directly to the hot pan as shown in Figure 17. This pretreatment dissolved much of the carbon immediately, allowing for easier cleaning and sanitizing. Whether or not this practice is performed in the field is unclear, but most cooks should know it is a reliable way to remove burned food from pans. The pre-wash did not influence longevity data on the coating because any damage to the coating had already taken place. Though it could be argued that pre-washing, which allows for slightly easier cleaning, would reduce the necessity to scrape the pans. At any rate, the procedure was carried out identically for each pan. Figures 18-20 show the condition of the pans after the pre-wash. Comparing Figure 19 and Figure 20, it can be seen that a significant portion of the carbon remained stuck to the uncoated pan versus the Teflon®, while almost none stuck to the Plasmadize® in Figure 18. The Plasmadize® was, however, significantly stained by these carbon deposits.

The cleaning and sanitizing process was performed manually, per field regulations. The hands on nature had the added benefit of allowing us to subjectively gauge which coating exhibited the best release properties. After Meal 1, cleaning the Plasmadize® coating was very easy. No food stuck to the pan and only a small layer of grease had to be washed off. The stains could not be removed from the coating. There was no evidence of peeling, or cracking of the coating but some evidence of slight pitting. These pits were hard to document with the camera used so a description will have to suffice. The pitting action was not the same as experienced in Figure 8. Plasmadize® after Salt Spray , rather these were small craters that seemed to form without the migration of metal through the coating. It is not clear if this was due to a loss in coating material, a collapse or denting of the base material under the coating or pores in the base metal that were simply filled by the coating during the coating process.

The Teflon® coating was also easy to clean. There were some solids loosely stuck to the coating but a soft sponge was enough to release them. There were no stains, but some discoloration was observed. There was no evidence of peeling, pitting or cracking of the coating.

The uncoated pan was very difficult to clean. The surface was firmly coated with carbon deposits from burned food. Some of carbon became impregnated in pits in the metal and could not be removed at all. It took significantly more time and effort to clean this pan

## Meal 1, Roast Beef with Carrots and Onions.

**Figure 12. New Plasmadize® (R) coating**

**Figure 13. New Teflon® coating**

**Figure 14. New uncoated pan**

**Figure 15. Food burned on Plasmadize®**

**Figure 16. Food burned on Teflon®**

**Figure 17. Food burned on Teflon® with water added**

**Figure 18. Plasmadize® (R), pre-washed**

**Figure 19. Teflon®, pre washed**

**Figure 20. Uncoated, pre-washed**

### 5.4.3. Meal 2 Discussion

Figure 21-Figure 29 show the results of the second meal, Swiss steaks. Swiss steaks are made by flouring and frying beefsteaks then braising them in tomato sauce. The lids of the pans were used to fry the steaks, and the roaster pans were used to cook the tomato sauce and then braise the steak.

Figure 21, Figure 22 and Figure 23 show initial condition of the pans. It is clear the pans did not become completely clean from the prior meal, particularly the Plasmadize® and uncoated pan. The black spots in Figure 23 indicate carbon deposits embedded in pores of the aluminum. In a field situation, a soldier would be told to scrape the pan with hard steel wool or a steel mesh pad until the metal shined. This scraping procedure was not followed because the coatings should not be intentionally scratched and it was important to the results use the same technique on each of the pans. The Plasmadize® pan is showing significant discoloration and evidence of forming pits.

Figure 24, Figure 25 and Figure 26 show the leftover tomato sauce from the Swiss steak meal. The acids from the tomato sauce coupled with the heat of long term cooking are the stresses for this test. Despite the attempts to overcook the sauce and have it stick to the pans, little sauce actually stuck to the pans. As shown in Figure 27, Figure 28 and Figure 29, a gentle pre-wash dissolved most of the tomato sauce leaving the pans relatively clean.

The sauce that remained was easily removed with a gentle sponge. However, there was some sauce stuck to the sides of the pans. This was the easiest to remove from the Teflon® pans, followed by the Plasmadize® and the uncoated pans. It was, however, not difficult to remove the stuck on sauce from the uncoated pans. The black char from the last test remained on the pan and was hard to remove from the corners.

It was following this test that the Teflon® was observed peeling away from the corners (Figure 30). It cannot be determined whether this was related to stirring with a metal utensil, the attack of the hot tomato sauce or scrubbing action. It is anticipated all of these factors may have played a part. Instead of ending the test at this point, another meal was planned to observe the effects of the peeling and whether or not the condition would worsen.

## Meal 2, Swiss Steak

**Figure 21. Plasmadize® initial condition**

**Figure 22. Teflon® initial condition**

**Figure 23. Uncoated initial condition**

**Figure 24. Plasmadize® w/ baked on sauce**

**Figure 25. Teflon® w/ baked on sauce**

**Figure 26. Uncoated w/ baked on sauce**

**Figure 27. Gently rinsed Plasmadize®**

**Figure 28. Gently rinsed Teflon®**

**Figure 29. Gently rinsed uncoated**

**Figure 30. Teflon® peeling away at the corners and fillets**

### 5.4.4. Meal 3 Discussion

The third meal consisted of chili con carne, also a food known to be high in fats and acids. Figure 31-Figure 39 show results for this meal. Figure 31-Figure 33 show that though the pans are clean, the Plasmadize® coating is still stained, the Teflon® coating is peeling in the corners and the uncoated pan has almost irremovable carbon deposits.

The chili was heated and served from the pans, and a small portion left over was cooked for 20 minutes longer until it became stuck to the sides of the pans. Though the food seemed to be stuck to the sides of the Plasmadize® and Teflon® pans, it peeled off with ease (Figure 34and Figure 35). This demonstrates excellent release properties.

Figure 37 and Figure 39 show the pans after cleaning; The Teflon® and Plasmadize® pans were effortless to clean. On the uncoated pan, chili residue was stubbornly fused to the sidewalls and. took significantly more time and effort to remove Figure 38 shows that enough time and effort were eventually spent on the pan over the three cleanings to remove most of the burned on food from the first meal.

## Meal 3, Chili Con Carne

Figure 31. Plasmadize® initial condition

Figure 32. Teflon® initial condition

Figure 33. Uncoated initial condition

Figure 34. Congealed food peels off

Figure 35. Congealed food lifts off

Figure 36. Food is stuck on

Figure 37. Cleaned Plasmadize®

Figure 38. Cleaned Teflon®

Figure 39. Cleaned uncoated

### 5.5. Conclusions

An overview of the results of these three tests is shown in Table 4. Neither of the two coatings passed qualitative testing with excellence. The mean time to failure for each coating was two meals. Although the Teflon® coating applied by Durafilm Inc. retained its nonstick property throughout the test, it began to flake and peel after just two meals and washings. It also incurred several stains. The Plasmadize® coating applied by General Magnaplate Inc. incurred several stains and some mild pitting. The stains on this pan were more prevalent because of the light color of the coating. Stains are not a sanitation issue but they are an annoyance that can very easily be mistaken for a sanitation issue in the field. Soldiers in the field may be inclined to wash and scrub a stained pan until it looked clean. The biggest problem with this coating is its thickness. The coating is so thick that the cover does not fit on the pan.

Though both products failed this testing, there is confidence an adequate product can be found for the application. More testing should be conducted on a variety of different coatings. Several variations of Teflon® and Plasmadize® exist that have very different properties than those tested. Furthermore, there are other coating families such as anodized, metallic, quasicrystal and diamond coatings that show promise and therefore should be tested qualitatively.

**Table 4. Summary of Results**

| Coating | Non-Stick | Adherence | Appearance | Comments |
|---|---|---|---|---|
| Teflon® | Nonstick property was conserved through all 3 tests | Began flaking after second meal and continued to flake | Somewhat stained after each meal | Teflon® as a brand name is applied differently by different contractors |
| Plasmadize® | Somewhat nonstick, no degradation over time | Good | Became increasingly stained | This coating is so thick that it is hard to put the cover on. |
| Uncoated | Impossible to remove burnt food, very hard to remove baked on food. | n/ap | Some discoloration due to heat. Black char from burnt food | |

## 6. Overall Results And Conclusions

The general trend displayed in these two tests suggests that commercial coatings are not yet sufficient for use in an Army field-feeding scenario. Both the quantitative and the qualitative seemed to discount the use of Teflon® or another pure PTFE coating. Although one can argue that the application of this coating was not of the highest quality, choosing a coating that cannot be applied by so many contractors, large and small, experienced and inexperienced, would be a risk. Furthermore, the general shape of the pan, with its steep filleted sides, does not lend itself to a PTFE application. The fillet is an obvious site of stress for the coating as was shown by the almost immediate flaking and peeling.

Each of the other coatings, except for the Tufram® coating, were discounted by a significant shortcomings in at least one performance criteria. The Nedox® failed the salt spray test, the Plazmadize® coating was too thick, and the friction coefficient of the anodized coating was too high. The qualitative tests discounted the plasma spray coating because of its tendency for becoming stained as well as showing signs of pitting.

More tests should be conducted on the Tufram® coating. This coating seems promising as a durable, nonstick coating for use in the field as it did very well in quantitative testing including showing strong wear resistance, low friction coefficients, extreme corrosion resistance and moderate hardness.

**Appendix. Summary of ASTM Test Methods**

| Test Method | Description |
|---|---|
| B 117 – 95 | Standard Practice for Operating Salt Spray (Fog) Apparatus |
| B 137 – 95 | Measurement of Coating mass Per Unit Area on Anodically Coated Aluminum |
| FED-STD-141.1 | Method 6192, Abrasion Resistance (Taber Abrasion) |
| B 487 –85(90) | Measurement of Metal and Oxide Coating Thickness by Microscopical Examination of a Cross Section |
| B 571 – 91 | Methods for Adhesion of Metallic Coatings |
| B 578 – 87(93) | Method for Microhardness of electroplated coatings |
| D 573 – 88(94) | Method for Rubber – Deterioration in an Air Oven |
| D 618 – 96 | Practice for Conditioning Plastics for Testing |
| D 1894 – 95 | Method for Static and Kinetic Coefficients of Friction of Plastic Film and Sheeting |
| D 3028 – 95 | Method for Kinetic Coefficient of Friction of Plastic Solids |
| D 3359 – 95a | Methods for Measuring Adhesion by Tape Test |
| D 3363 – 92a | Method for Film Hardness by Pencil Test |
| D 4060 – 95 | Method for Abrasion Resistance of Organic Coatings by the Taber Abraser |
| D 4518 – 91 | Methods for Measuring Static Friction of Coating Surfaces |
| E 10 – 96 | Method for Brinell Hardness of Metallic Materials |
| E 18 – 94 | Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials |
| E 140 – 95 | Standard Hardness Conversion Tables for Metals |
| E 384 – 89 | Method for Microhardness of Materials |
| E 1131 – 93 | Method for compositional Analysis by Thermogravimetry |