TUFRAM®

Surface Enhancement Coatings Protect Aluminum and Aluminum Alloys Against Wear, Corrosion, Sticking and Galling

- Dramatically increase surface hardness
- Resist corrosion, chemicals, and acids
- Prevent abrasive wear and galling
- Provide superior mold release
- Meet AMS 2469 and AMS 2482
- Offer high dielectric strength
- Permanently self-lubricating for extended wear
- Many meet FDA, USDA, NSF, and AgriCanada codes
- Speed cleanup and sanitation maintenance
- No outgassing in the vacuum of space
- Low COF eliminates sticking and product "hang up"
- Won't chip, peel, or flake off like "paint-ons"
- Meets the End of Life Vehicle (ELV) initiative for the automotive industry

Although TUFRAM coatings were used to solve critical wear and performance problems plaguing aluminum parts on NASA's space vehicles, engineers worldwide soon recognized them as the solution to a host of problems faced by aluminum components on all types of manufacturing, processing and packaging equipment.

Created in a proprietary, multi-step process that makes aluminum surfaces harder than steel, TUFRAM coatings combine the hardness of aluminum oxide ceramic with the desirable properties of selected Magnaplate proprietary polymers to give aluminum parts previously unattainable levels of hardness, wear and corrosion resistance, as well as permanent lubricity.

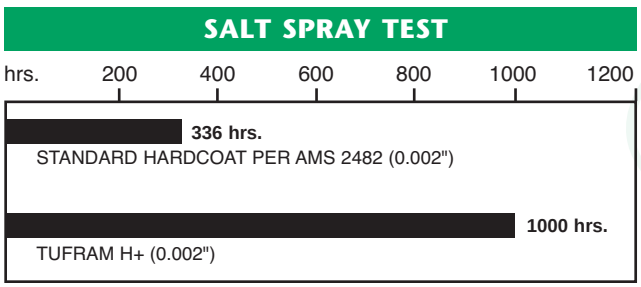
Since the surface is superior in performance to both the aluminum or any of the individual components used in the process, Magnaplate-applied TUFRAM coatings are identified as "synergistic."

Engineering Data and Performance Characteristics

Corrosion resistance

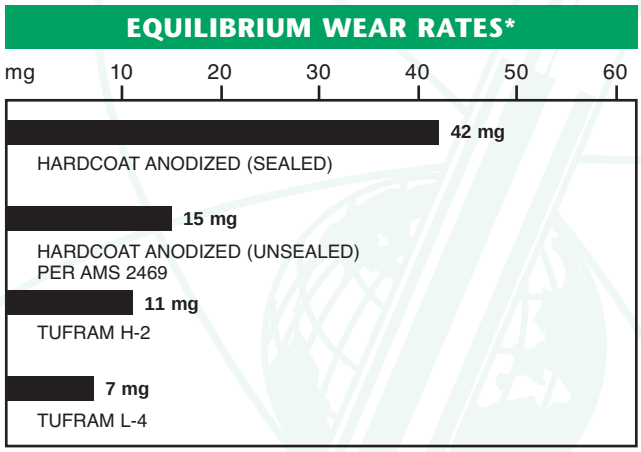
TUFRAM coatings exhibit much greater corrosion resistance than conventional hard anodizing. Some types show extremely high resistance to most common chemicals and salt spray. Tests show no effect after 168 hours immersion in Aqua Regia at 248°F (120°C). A TUFRAM-coated surface showed almost no corrosive activity after prolonged, continuous exposure to the atmosphere and salt water. In addition, TUFRAM enhancements on high strength aluminum exceed the AMS 2482 requirement of a minimum of 336 hours in salt spray.

When maximum corrosion resistance on aluminum is required, MAGNAPLATE HCR®, which provides 40 times the required protection, is recommended.



Abrasion resistance

A smooth surface substrate produces the most abrasion-resistant TUFRAM finish. Taber abrasion measurements show that its wear resistance is far better than either case-hardened steel or hard chrome plate. No matter what other metal rubs against the TUFRAM coating, it too will show only slight wear.



*Using Taber Abrasion, WEIGHT LOSS = mg. per 10,000 cycles
CS-17 wheel, 1000 gm. load

Friction

In some cases, the static friction decreases with an increase in load. TUFRAM eliminates "stick-slip" and undesirable vibration of higher break-away friction. For more information, see General Magnaplate's Friction Data Guide.

TUFRAM FRICTION CHART

Material	Vs.	Material	COF Static	COF Kinetic
Aluminum		Aluminum	0.42	0.34
Aluminum		TUFRAM HO	0.25	0.22
TUFRAM H2		TUFRAM H2	0.17	0.14
TUFRAM L4		TUFRAM L4	0.18	0.17

Hardness

Varies from equivalent hardness of Rc 40 to Rc 65, depending on the TUFRAM chosen and alloy used.

Adherence and impact resistance

TUFRAM coatings adhere firmly to most alloys, especially those containing magnesium. Impact resistance is limited only by the structural strength of the base metal to which they are applied.

FDA/USDA/NSF/AgriCanada compliance

Compliance with FDA, USDA, NSF, and AgriCanada codes makes most TUFRAM coatings advantageous for food and pharmaceutical processing and packaging, and some medical industry applications.

Temperature

Exhibits high strength, toughness, and self-lubricity down to –360°F (–218°C), and intermittent operating capability at temperatures as high as +800°F (+427°C), depending upon the process specified and the alloy used.

Non-stick release properties

Very few solid substances, even adhesives, adhesive-backed products or glues, will permanently adhere to the proprietary-polymer-impregnated surface of a TUFRAM-coated part. Most substances, such as plastics, rubber or slurries, release easily. Some extremely tacky materials may exhibit mild temporary adhesion.

Self-lubricating surface

Proprietary polymers impregnated into the aluminum during the TUFRAM process level off surface asperities to provide a permanent self-lubricating surface, and result in greatly reduced surface tension. TUFRAM-coated parts exhibit a longer wear-life, require less maintenance, and provide greater operating efficiencies with less downtime. Mating parts that operate with a sliding or rotating motion experience a dramatic reduction in friction.

Thermal conductivity

Aluminum that has been coated with TUFRAM exhibits rapid heat and cold transfer. By converting the original single flat crystal into millions of surface facets, the TUFRAM process permits heat distribution within the encapsulated outer surface far better than that of untreated aluminum. Some of the proprietary polymers impregnated into the TUFRAM coating have a heat conductivity of 1.7 ± .03 Btu/hr/sq ft/deg F/in. Selective processing permits wide ranges of conductivity for heat sink applications.

Resistance to acid and alkaline solutions

TUFRAM 600 Series coatings provide superior resistance to attack from acid or alkaline solutions and atmosphere. In humidification tests, panels with one edge exposed by a saw cut were immersed in acid with a pH range of 3.5 – 4.0 and in an alkaline solution with a pH range of 8.5 – 9.0. Both panels protruded for half their lengths to provide immersion and vapor tests simultaneously. After 90 days, saw cut edges on both panels were badly corroded. Heaviest damage occurred at interfaces of the liquid and vapor states. However, TUFRAM-treated surface areas showed no effect.

Non-wetting

The new, integral surfaces are oleophobic and hydrophobic, and resist wetting by most liquids. Cleanup is faster, easier, and more thorough. Parts become self-cleaning. Maintenance time and labor are greatly reduced.

Weather resistance

Tests of TUFRAM-coated samples, exposed for years to severe climatic conditions, confirm its resistance to all types of weather. TUFRAM coatings also exhibit excellent resistance to ultraviolet light and extreme heat.

Performance in vacuums

TUFRAM coatings have been applied to parts on every space vehicle. They are required to perform in extreme environments, including vacuums to 10^{-6} torr and temperatures from –100°F (–73°C) to +350°F (+177°C), and under conditions of extreme vibration. Today, they are used in vacuum packaging and on machinery that must operate under vacuum.

Ultra-Thin TUFRAM 2000™

Offers all these special features and benefits in one ultra-thin coating!

- Precision with .0003 – .0007" thicknesses (.00015 – .00035" buildup)
- Superior resistance to wear (4.68/10,000 cycles)
- No chrome — environmentally friendly
- Excellent corrosion resistance (2,500 hrs.)
- USDA/FDA-compliant
- Sealed or unsealed versions
- Retains excellent thermal conductivity of aluminum
- Creates an effective dielectric barrier
- For complex geometric shapes
- Dense and uniform oxide layer with accurate control via micro processors
- Meets performance requirements of AMS 2469

Application to aluminum alloys

Aluminum and its alloys that contain less than 5% copper and 7% silicon and that do not contain excessive zinc or lead are most suitable for the application of TUFRAM coatings. Most cast, forged, extruded or wrought alloys can be treated. The degree of hardness or penetration does vary with some alloys.

Coating tolerances / thickness

With few exceptions, a consistently uniform coating can be applied to parts of any configuration or weight, and virtually any size or thickness. Precise control of thickness permits use on threaded members and similar close-tolerance applications. By undersizing outside pitch diameter by roughly twice the coating thickness prior to coating, original thread sizes are maintained.

For machining allowances, note that overall final thickness of the coating is influenced by two factors:

A. Penetration **B.** Surface Growth

The table below shows typical examples:

COATING Thickness in Inches	SURFACE Growth in Inches*
0.0008	0.0004
0.0010	0.0005
0.0020	0.0010

*Note: Growth is approximately 50% of the thickness value.

Thickness is customized for each application. Maximum thickness is limited by alloy composition. Minimum practical thickness is 0.0005".

Dielectric properties

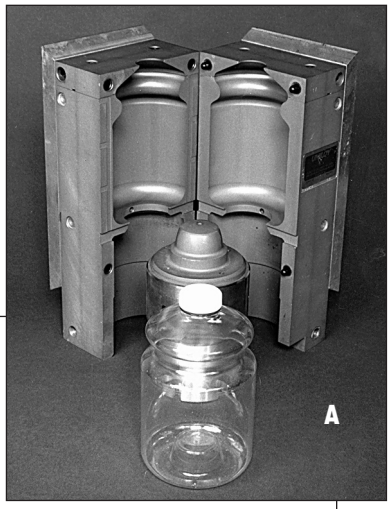
The TUFRAM process converts the aluminum surface to one with excellent dielectric characteristics, without affecting the high conductivity of the parent metal. The proprietary-polymer impregnation imparts outstanding properties as an insulator. The polymers do not absorb water. Volume resistivity values remain unchanged, even after prolonged soaking in water. Surface resistivity values were taken at 100% relative humidity. Dielectric constant for the polymer remains constant at 2.1 for a temperature range of –250°F (–157°C) to +550°F (+288°C) and a frequency range of 5 Hz – 10,000 MHz. Dissipation factor is also constant at 0.0003 for the same ranges of temperature and frequency. Non-conductive TUFRAM acts as an insulator that withstands a range of 500 – 2,000 volts, depending upon thickness.

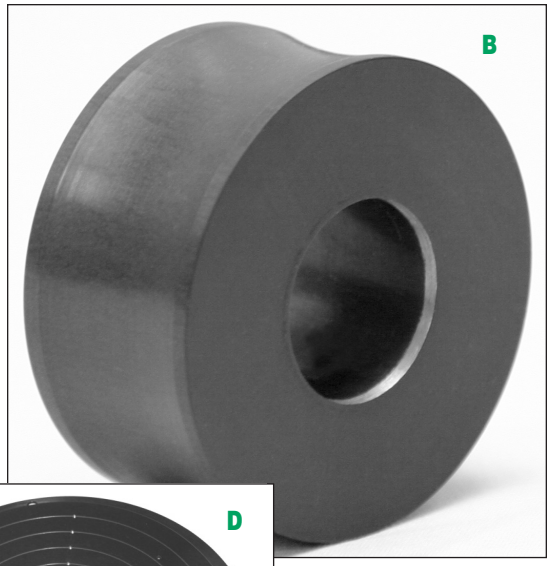
TUFRAM FAMILY OF "SYNERGISTIC" COATINGS

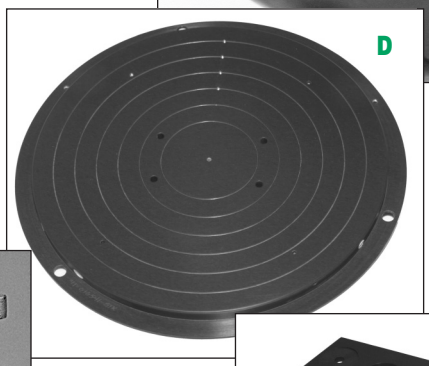
FC-12	Special combinations of polymers and dry lubricants allow low COF.
H-2	Maximum hardness (Rc 60 – 65).
HCD-31	High dielectric strength.
H-O	Hard (Rc 40 – 50), wear resistant, dry lubricated surface. Good release. USDA/FDA/NSF/AgriCanada-compliant.
H+	High strength aluminum (T-6) maintains maximum hardness, corrosion resistance and lubricity.
L-4	Minimizes "stick/slip".
R-66F	Permanent mold and sealing surface release. USDA/FDA/NSF-certified.
604	Chemical resistance and mold release. USDA/FDA-compliant.
611	Tough. Easy to clean. Available in colors. USDA/FDA-compliant.
615	Maximum release properties. Operating temperatures to 550°F (288°C). Sparkling black or white color. USDA/FDA-compliant.
2000	Excellent thermal conductivity. Effective dielectric barrier. For complex shapes. USDA/FDA compliant.

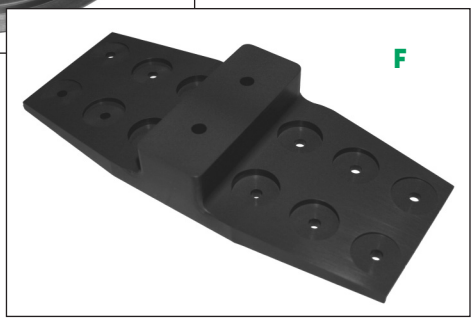
- Intermediary combinations and permutations of these characteristics can be formulated to specific order.
- Finish color may vary depending on base alloy, coating selection, and thickness.
- Meets and exceeds AMS 2469 and AMS 2482.
- For maximum salt spray resistance, see separate MAGNAPLATE HCR® brochure.

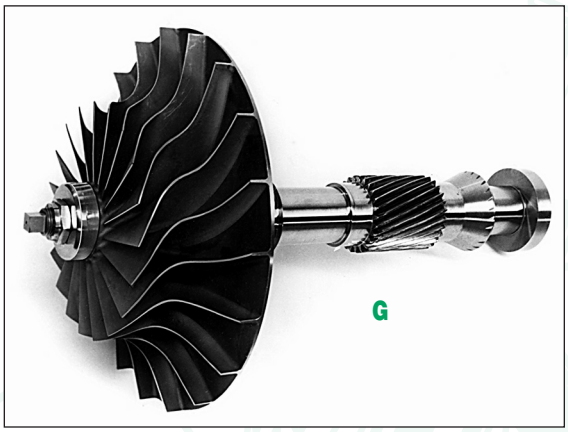
Examples of TUFRAM Coatings in Use











A. *TUFRAM on aluminum sections of Johnson Controls' bi-metallic PET bottle molds prevent erosion and galvanic corrosion causing poor release, high reject rates and shortened mold life. Steel sections were treated with Magnaplate's NEDOX®.*

B. *TUFRAM coating is used in severe abrasive environments. This roller guide is used to manufacture cardboard tubing. TUFRAM coatings run on Taber abrasion testing units have produced weight loss numbers as low as 0.5 mg per 1000 cycles (Fed Std. #141).*

C. *TUFRAM is used on this pneumatic shifter to reduce the friction as the accompanying piston runs against it. The shifter is used on aircraft towing vehicles, which operate under substantial loads.*

D. *TUFRAM coatings are excellent in vacuum environments. This wafer chuck was coated with TUFRAM to provide a wear resistant coating that would not generate particulate under vacuum, enabling contamination-free wafers to be manufactured.*

E. *TUFRAM coatings protected aluminum fuel mixing control valves on the LEM Ascent Engine against vibration and "outgassing" under operating conditions of 10^{-6} torr vacuum and –100°F (-73°C) to +350°F (+177°C) temperature variations.*

F. *TUFRAM was used on an aircraft centrifuge component to reduce friction and increase the wear resistance.*

G. *Aluminum air compressor impeller blades exhibit longer wear life, reduced drag, and improved airflow after being coated with TUFRAM to protect them against corrosive and erosive chemical process industry gas streams.*

Tomorrow's Materials Solutions... Today.®

General Magnaplate

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