

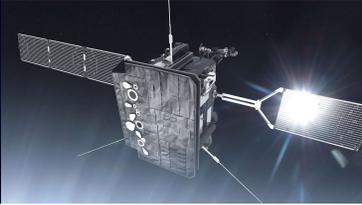


ENBIO

www.enbio.eu

CoBlast SolarBlack Thermal Control Coating Implementation Project

(From the Valley of Death.....to Space in just 3 years)



About ENBIO

ENBIO Ltd. is headquartered in Dublin, Ireland with a dedicated US entity. The company, founded in 2006, is the inventor and trustee of a remarkable technology called CoBlast. CoBlast offers multiple industries the ability to redefine the performance, function and value of metals across all sectors. ENBIO is a young and vibrant company, operating as a trusted partner in some of the most regulated and demanding markets, including the Space sector. ENBIO's mission is to develop and deliver enhanced metal surface technologies for the global marketplace. The company has developed a portfolio of applications using a one-step, simple, sustainable and economical process via their innovative patented CoBlast technology. Their next-generation solutions meet ever increasing global regulatory requirements including REACH, while meeting the most stringent performance requirements.

About CoBlast

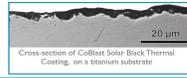
CoBlast is an environmentally friendly process, requiring no chemical, vacuum or thermal inputs. CoBlast is a proprietary surface modification technique that involves the coincident bombardment of a surface with both an abrasive medium and coating material to be deposited. The abrasive media is utilized to remove the metal's passive layer in the presence of the deposited coating material. This allows for the abrasive media to remove the oxide layer and provide surface roughness while simultaneously introducing the coating to a oxide free metal surface in a one-step process.

CoBlast transforms the metal's performance, function, value

- Remove the oxide layer
- Roughen the metal surface
- Apply unique coating



UNIQUE ONE-STEP PROCESS



THE PROCESS

One Step.....Similar to Grit Blasting

- Ambient temperature
- Ambient pressure
- Normal atmosphere
- Dry chemical - No wet chemistry
- Line of Sight
- Single piece of equipment
- Selective chemistries for various applications
- Adhesion Promotion
- Corrosion Resistance
- Thermal Control
- Mould Release

- Solvent Free - No VOCs, HAPs, or Waste Water Treatment
- Zero Water Use
- Zero GHG Emissions
- Non-Flammable
- Long Material Shelf Life
- Material can be Recycled
- Low Energy Consumption
- Minimal PPE
- Scalability
- Automation

CoBlast provides a simple, environmentally safe, innovative method of enhancing the performance of a metal surface

Project Requirement: Develop and Qualify Thermal Control Coating

- High Absorptivity/High Emissivity
- Thermal and UV Stable
- Electrically Conductive
- No Outgassing/ No Particulates
- Environmentally Friendly -REACH Compliant

Scheduled for launch in 2020, the European Space Agency's (ESA) Solar Orbiter (SoI0) spacecraft will study the Sun at unprecedented close proximity - approximately 26 million miles. Such an extreme temperature and radiation environment, required the Agency to seek and qualify suitable next-generation thermal protection systems.

In 2011, ESA and Airbus Defence and Space began collaborating with ENBIO Ltd. to specifically develop a high-absorptivity/high-emissivity (flat absorber) thermal control surface coating. SolarBlack is a calcium phosphate surface modification applied to the outermost titanium foil of the multi-layered heat shield using ENBIO's novel patented CoBlast technology. It is critical that the SolarBlack maintains its thermo-optical properties throughout years of exposure to extreme infra-red and ultraviolet radiation, whilst not shedding material or outgassing vapor, which would risk contaminating the SoI0's highly sensitive instruments. Additionally, it needs to be electrically conductive to avoid the build-up of static charge, threatening the mission with a destructive discharge event.

In May of 2014, after undergoing and completing an extreme test process at the ESA/ESTEC in the Netherlands, ENBIO's CoBlast SolarBlack was approved for use on flight hardware and was awarded the contract to coat the main heatshield for ESA's SoI0. Some of the test results of that project are summarized here. Three years is an extremely short and unprecedented duration for a critical space application to go from concept to flight hardware approval.



Above - ESA's SoI0 team watch as a part coated with ENBIO's SolarBlack is lowered into Large Space Simulator at ESTEC. Top Right: ENBIO Space Technologies Centre in Clonmel, is ENBIO's centre of excellence for the production of Thermal Management treatments for satellites, spacecraft, and space related hardware. Bottom Right: Stepped section of Titanium SoI0 component with CoBlast SolarBlack. Bottom Left: Stepped section of bare Ti SoI0 component bare, no coating

Testing

Outgassing (%)

CVCM: 0.001 RML: 0.03

Vacuum thermogravimetric (VTGA) at Advanced Aerospace and Composites GmbH. ECSS-Q-ST-70-02C require the recoverable mass loss (RML) and CVCM of any test material must not exceed 1.0 and 0.10% respectively.

Solar Absorption α_s

Titanium = 0.96 - 0.97

SolarBlack coated Ti-6Al-4V coupons and foils were measured to be 4% and 3% respectively corresponding to solar absorptance values of 0.96 and 0.97 (+/- 0.02). Verified at European Space Research and Technology Centre (ESTEC) IAW ESA ECSS-Q-70-09C and ASTM E490.

UV/VUV

Sample temperature: 540°C during testing

UV Exposure: 26000 Equivalent Sun Hours (ESH) VUV: approx 19,500 ESH

Electron radiation: 234 hrs at 60KeV and 0.5 nA/cm2 Proton: 2.5 hrs at 60KeV and 1 nA/cm2

Beginning of Test (BOT):

Alpha: 1mm titanium - 0.96; 50um - 0.96 Epsilon: 1mm titanium - 0.78; 50um foil - 0.81

End of Test (EOT):

Alpha: 1mm titanium - 0.96; 50um - 0.96 Epsilon: 1mm titanium - 0.78 ; 50um foil - 0.81

Thermal Emissivity

The thermal emissivity of SolarBlack was determined IAW ESA ECSS-Q-70-09C as 0.81 +/- 0.03 at room temperature and increased to 0.91 at 600°C. Uncoated and grit blasted samples were measured to be 0.18 and 0.48 +/- 0.03 respectively at room temperature. SolarBlack possesses an α_s/ϵ_N ratio of 1.19 to 1.20.

Electrical Resistivity

Determined at an electrical potential of 1V using an Agilent 4338 B resistance meter in conjunction with a 16008B concentric ring probe was determined to be $10^2 \Omega/sq$, well beneath the electro static dissipation requirements ($\rho_s < 10^9 \Omega/sq$) required to prevent an electro static discharge event in service.

Adhesion

No spalling, delamination or particulate release was observed subsequent to peel testing. Clean tape separation was observed across all specimens when examined at 7x magnification post Fast Thermal Cycling (see conditions below) IAW ECSS-Q-ST-70-13C specification

SolarBlack was applied to coupons which were subjected to thermal cycle testing using the Fast Thermal Cycling (FTV) Facility in ESTEC under the following conditions.

Temperature Range: 100-700°C

Vacuum 10^{-6} bar

Heating/cooling ramp rates: $10^\circ C/min$

Dwell: 60 min @ $700^\circ C$

Dwell: 120 min @ $100^\circ C$

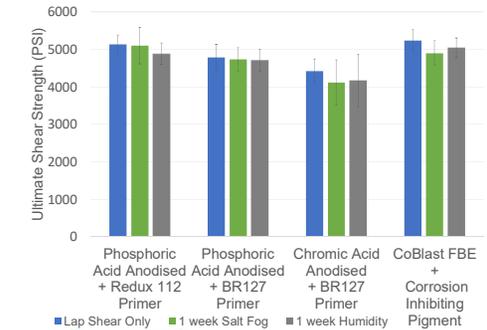
Cycles: 20



Additional CoBlast Applications - OSMOSIS Project Adhesion and Corrosion Resistance

OSMOSIS (One-Step Modification of Space Integrated Surfaces) is another ambitious project which utilizes the unique CoBlast surface coating technology to bring a viable chromate free adhesion promoting and corrosion inhibiting alternative solution through full commercialization to the European Space Sector within a period of two years.

The EU's stringent REACH regulations, which require the elimination of hexavalent chromium and other toxic materials, have propelled CoBlast to expand into evaluating a range of organic and inorganic materials in this application. Initial work testing of CoBlast on aluminum coupons, both before and after humidity ageing and salt fog exposure, are shown in comparison to current standard chromated processes



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 757088

For more information on any of the data summarized here, ENBIO's SolarBlack coating, or CoBlast for adhesion and corrosion inhibition, Please Contact our US representatives

Fergal O'Moore
President US Operations
fergal.omoore@enbiomaterials.com
408-966-1495

Dayna Lamb
VP Sustainability
dayna.lamb@enbiomaterials.com
520-245-2445