Technion – Israel Institute of Technology

- Founded in 1912
- 18 faculties, ~60 research centers, 15K students
- 3 Noble prizes (Shechtman, Hershko and Ciechanover)
- 5 teaching campuses: Technion (Main)- Haifa IL, Technion (Medical)- Haifa IL, Technion continuous education- Tel Aviv IL

# Technion Guangdong Institute of Technology - Shantou, China
# Cornell Tech – New York, USA
Technion’s Israel Institute of Metals

- **Applicative R&D** in the field of metals.
- Industrial services under ISO 17020 and testing under ISO 17025.
- Main research laboratories:
  - Surface & Corrosion, Foundry, Metallurgy and Tribology.
- Additive Manufacturing R&D Center.
- Tech-Med Center.
Advanced Surface Protection for Extreme Environments

Project: Micro Arc Oxidation of Aluminized Carbon Steel

- Collaboration with PCT – Protective Coatings Technology.
- Project was supported by the Israel Innovation Authority, Ministry of Economy & Industry.

E-MRS Fall 2017
Micro Arc Oxidation

- Also known as Plasma Electrolytic Oxidation (PEO).

- Converts the metallic surface into a thin, dense and very hard ceramic layer - resistance to corrosion and wear.

- Secondary sealing processes enhance chemical resistance against a wide range of chemicals at a variety of temperatures.

- Traditionally the MAO process can be applied only to light metals. Aluminization process enables applying the MAO coatings to carbon steel.
How Does MAO work?

An electrochemical oxidation process - high voltage and high current controlled process.

Immersion in a alkaline electrolytic bath of proprietary composition.

Intense plasma is created by micro arcing at the component surface.

These micro-arcs reach extremely high temperatures (>5000°C) and convert the surface into a unique blend of a very dense amorphous and ultra-hard crystalline ceramic structure.

Underlying substrate material is unaffected.
## MAO on aluminum

### PROCESS PERFORMANCE

<table>
<thead>
<tr>
<th>Typical Dimensions</th>
<th>80 – 300 micron. The conversion coating grows partly above the surface and partly below, resulting in a uniform, conformal coating applicable on complex component geometries.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compatibility</td>
<td>The coating can be applied on all aluminum alloys. The properties of the coating may be influenced by the type of the alloy.</td>
</tr>
<tr>
<td>Safety</td>
<td>The process is environmentally friendly, containing no acids, lead, chromates and toxic chemicals.</td>
</tr>
</tbody>
</table>

### COATING PERFORMANCE

<table>
<thead>
<tr>
<th>Surface Characteristics</th>
<th>Hydrophilic surface with high adhesive strength.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness</td>
<td>1,500 - 1,700 HV (depending on the alloy and thickness of the layer).</td>
</tr>
<tr>
<td>Wear Resistance</td>
<td>Passed Abrasion Taber Test acc. to MIL STANDARD 8625.</td>
</tr>
<tr>
<td>Corrosion</td>
<td>4,000 hours by Salt Spray Test (SST) (depending on the alloy) according to ASTM B117.</td>
</tr>
<tr>
<td>Temperature</td>
<td>Up to thermal treatment temperature of the alloy.</td>
</tr>
</tbody>
</table>
Other benefits

No surface preparation.

Protects against short, high-temperature flashes.

Complex geometries & internal surfaces.

Technology is compatible to large components.
Development of MAO Process for Aluminized Steel

Aluminization using hot-dip method

1. Diffusion of Al to the steel.
2. An intermetallic layer to increase adhesion.
3. Surface Al layer to allow the MAO process.
4. MAO process oxidizes the upper Al layer.

Aluminization using TSA method (+ PCT2000 layer)

✓ Layer thickness: 100-150 µm
✓ Layer micro-hardness up to 1600 HV.
The Challenge

- $\delta_c$ - critical value where cracks start to penetrate ($\delta$ – crack opening displacement “COD”).

- Cracks initiate on the Fe-Al layer-substrate interface and the crack propagation is blocked by the Al layer (this plastic layer delays cracks to penetrate the ceramic layer).

- The idea is to have a sufficient Al layer with resistance for crack propagation.

- Control of the thickness ratio $t_{Al}/t_{Al_2O_3}$ is the key to improve the toughness and strength of the aluminized steel.

Crack Propagation Model, after Z. Chen et al. Materials Science and Engineering A 528 (2011) 1409–1414
The Challenge

In our project:
Optimized process was developed, with controlled thickness ratio and without cracks.

Constant dipping time

Constant dipping temperature
MAO on steel - Characterization

> 2,400 hours in Salt Spray Test (ASTM B117)

Taber abrasion test (ASTM 4060):
After wearing off the technological layer, the abrasion rate is reduced and stabilizes below 10 mg per 1000 cycles.

The layer thickness can be increase as required to prolong the lifetime under wear conditions.
**MAO on steel – Summary of Properties**

**PROCESS PERFORMANCE**

<table>
<thead>
<tr>
<th><strong>TYPICAL DIMENSION</strong></th>
<th>60 - 200 micron.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COMPATIBILITY</strong></td>
<td>The layer can be coated with PCT 1000 and PCT 2000.</td>
</tr>
<tr>
<td><strong>SAFETY</strong></td>
<td>The process is environmentally friendly.</td>
</tr>
</tbody>
</table>

**COATING PERFORMANCE**

<table>
<thead>
<tr>
<th><strong>SURFACE CHARACTERISTICS</strong></th>
<th>Aluminum is metallurgically bonded to the steel surface, providing excellent heat reflectivity and corrosion protection.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HARDNESS</strong></td>
<td>700 – 1,500 HV depending on the process.</td>
</tr>
<tr>
<td><strong>CORROSION</strong></td>
<td>Up to 2,400 hours by Salt Spray (SST) method.</td>
</tr>
<tr>
<td><strong>TEMPERATURE</strong></td>
<td>Aluminized Steel resists heat and oxidation up to 900° F (482° C) without discoloring and maintains its strength at temperatures up to 1250° F (677° C).</td>
</tr>
<tr>
<td><strong>WEAR RESISTANCE</strong></td>
<td>Tested and passed Abrasion Taber Test acc. to MIL. STANDARD 8625.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HV</th>
<th>Spot</th>
<th>WD</th>
<th>Mag</th>
<th>Det</th>
<th>Sig</th>
<th>Pressure</th>
<th>PCT2000 plate</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.0 kV</td>
<td>4.0 mm</td>
<td>9.2 mm</td>
<td>800x</td>
<td>SSD</td>
<td>BSE</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>
Functionalization Using Special Sealers

- Chemically resistant to inorganic and organic media, strong acids, caustic solutions, gases and water vapor.
- Enhanced wear resistance.
- Smoother surface appearance, primers and colors.
- Variable friction coefficient.
- Conductive surface.
Applications – MAO on Al

MAO coatings are used as a replacement for anodizing.

Type I (chromic acid) and II (sulfuric acid) are used for corrosion protection, type III where increased hardness is needed (hard anodizing).

✓ MAO coating are harder and smoother.
✓ Can be also used as electrical insulators and have excellent heat resistance.
✓ Environmental protection is much higher in MAO Process, while the equipment costs are lower.
✓ PCT algorithm reduces the required energy to produce MAO coating.
Applications – MAO on Steel

- Nuclear applications: aluminized steel + MAO to reduce stress corrosion cracking (SCC).

- Oil & gas applications: corrosion and wear resistant in extreme conditions.

- Water treatment: major use of aluminum-MAO pipes (IDE). This technology can be used for steel pipes or other equipment.
Thank you very much