Atomic Oxygen Cleaning of Unpainted Plaster Sculptures

Bruce A. Banks¹
Sharon K. Miller²

¹Science Applications International Corporation at NASA Glenn Research Center, Cleveland, Ohio, USA
²NASA Glenn Research Center, Cleveland, Ohio, USA

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Gypsum/Plaster of Paris Composition

Gypsum/Plaster of Paris is a crystalline mineral of hydrated calcium sulphate

\[ \text{CaSO}_4 \cdot 2\text{H}_2\text{O} \]
Atomic Oxygen Removal of Organic Surface Contaminants

Organic contaminant → Inorganic substrate → Cleaned surface

O O O → OH H₂O CO CO₂ →
Atomic Oxygen Interactions with Hydrocarbons

All atomic oxygen reactions result in release of volatile oxidation products

### Alkanes

- **Abstraction**: $R\text{CH}_2\text{CH}_2 + \text{O} \rightarrow \text{RCH}_2\text{CH}_2\cdot + \text{HOH}$
- **Replacement**: $\text{R'O} \rightarrow \text{R''CH}_3\cdot$
- **Insertion**: $[\text{RCH}_2\text{CH}_2\text{OH}]^* \rightarrow \text{Fragmentation (Volatiles)}$

### Alkenes

- **Abstraction**: $\text{RCH} = \text{CHR} + \text{O} \rightarrow \text{RCH} = \text{CHR}\cdot + \text{OH}$
- **Addition**: $\text{RCH} = \text{CHR} + \text{OH} \rightarrow 2 \text{RCH}_2\text{CH}_2\cdot + \text{HOH}$
- **Elimination**: $\text{RCCH}_2\cdot \rightarrow \text{H}^+ + \text{Volatile}$
- **Triplet-Singlet Interconversion**: $\text{RCH} = \text{CHR} \leftrightarrow \text{RCCH}_2\cdot$
- **Epoxide Formation**: $\text{RCCH,O} \rightarrow \text{Fragmentation (Volatiles)}$
- **Fragmentation (Volatiles)**
Radio Frequency Plasma Ashers
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Radio Frequency Plasma Asher
Large Area Atomic Oxygen Exposure Facility
Schematic of Large Area Atomic Oxygen Exposure Facility

13.56 MHz RF generator

Powered electrode

Ground electrode with samples

Surface to be cleaned

Air inlet valve

Air inlet

Roughing pump
Exposure Configuration in Large Area Atomic Oxygen Exposure Facility
Radio Frequency Plasma in Large Area Atomic Oxygen Exposure Facility
Atomic Oxygen Art Restoration of Smoke Damaged Paintings

Before atomic oxygen cleaning

After atomic oxygen cleaning
Atomic Oxygen Art Restoration of Fire Damaged Paintings

Fire damaged

After atomic oxygen restoration
Pine

Untreated  Atomic oxygen etched
Plaster Sample Preparation

Plaster used

Plaster in molds
Plaster Sample Preparation

Pristine

Candle soot coated
Plaster Sample Cleaning Results
Candle soot coated

Before atomic oxygen cleaning

After atomic oxygen cleaning for 15.8 hours
Plaster Sample Cleaning Results

Candle soot coated on sanded back surface of samples

Pristine  Soot coated  After atomic oxygen cleaning
For 15.8 hours
Plaster Sample Preparation

Rubbed with contaminants from automobile exhaust pipe

Rubbed with contaminants from automobile engine oil on engine block
Plaster Sample Preparation

Rubbed with contaminants from automobile exhaust pipe

Rubbed with contaminants from automobile engine oil on engine block
Plaster Sample Atomic Oxygen Cleaning Results

Before

Rubbed with contaminants from automobile exhaust pipe

After

Rubbed with contaminants from automobile engine oil on engine block
Pencil and Pen Markings on Sanded Smooth Samples

Marked samples

After atomic oxygen cleaning

- Black Sharpie
- B1 Pencil
- #2 Pencil
- Paper mate ball point pen
- Paper mate ultrafine flair pen
- Pilot precision gel pen
- Red Sharpie
Summary

• Atomic oxygen appears ideally suited to remove hydrocarbon contamination from the surface of plaster sculptures.

• If the hydrocarbon contamination has inorganic content, atomic oxygen cleaning may leave some traces of inorganic residue on the surface.

• There is no abrasion to the plaster sculptures during cleaning with atomic oxygen.

• The highly reactive atomic oxygen is able to get around corners and into crevices.

• The reaction products with pure hydrocarbons are simple dilute gases leaving no contamination on the surfaces of the plaster sculptures.

• The cleaning process can be stopped at any point so that a surface can be partially or fully cleaned in order to obtain the desired color on the surface.