IMPROVING MUSICAL INSTRUMENT STRING LONGEVITY WITH ORGANOSILANES

TONY PARKER
A. A. Parker Consulting, LLC
Newtown, PA

CALEN BRUCE and
DAVE MARIASY
Team Audio, Inc., Toledo, OH

Presented at the Seventh International Symposium on Silanes and Other Coupling Agents; University of Maine, July 16, 2009
Organosilanes in Product Development Applications

Hydrophobic Coatings for Inorganic Powders
(U. S. Patents 7,387,795; 5,543,173; 5,348,760)

Safety Glass
(U.S. Patent 5,747,617)

Floors
(U.S. Patent 6,413,618)

Coatings
(U.S. Patent 6,759,096)

*Musical Instrument Strings
(U. S. Patent 7,476,791)

Protein-based Adhesives (Patents Pending)

Self-assembled Monolayers

©2009 A. A. Parker – Page 2; www.aaparkerconsulting.com
Silane Treated Strings

ORGANOSILANE TREATED STRINGS
(U. S. Patents 7,476,791 & 6,348,646)

© 2009 A. A. Parker – Page 3; www.aaparkerconsulting.com

A. A. Parker Consulting, LLC
Improving Musical Instrument String Longevity with Organosilanes

GENERAL CHEMISTRY

$\text{EtO-Si-OEt} \xrightarrow{\text{H}_2\text{O}} \text{HO-Si-OH} + 3 \text{EtOH}$

$\text{Si-O-Si-O-Si-O-Si-O-Si-O-Si-O-Si-O-Si-O-Si-O-Si-O-Si-O-Si}$
The corrosion of metallic musical instrument strings has been a problem for more than 100 years. Analytically, the vibration of an ideal string can be expressed as follows:

\[ f(n) = \frac{n}{2L} \left(\frac{T}{m}\right)^{1/2} \]

- \( f \) is the vibration frequency
- \( n \) represents the overtone vibration (\( n = 1 \) for the fundamental tone)
- \( L \) is the speaking length between end-points (25.5" for a typical guitar)
- \( T \) is the tension on the string (higher tension produces higher frequencies)
- \( m \) is the mass per unit length (heavier strings vibrate at lower frequencies)


Corrosion byproducts lead to vibrational damping

Overtones are the most sensitive (overtones affect “brightness”)

Polymer coatings have been employed – damping is a problem
MUSICAL INSTRUMENT STRINGS AND CORROSION

The Advantages of Organosilane Surface-Treated Strings

(U. S. Patent 7,476,791)

Enhanced Longevity – Strings resist corrosion (salt & moisture from hands)

Improved Sound Quality – No damping (< 0.1 % mass by string wt. vs. 3.5 % for conventional polymer-coated strings)

Better mechanical integrity than thicker polymeric coatings

Longer Resonance Times (slower vibrational decay)

Versatile Chemistry – Works on Steel-Core & Titanium-Core Strings (Ti is always the best)
Improving Musical Instrument String Longevity with Organosilanes

MUSICAL INSTRUMENT STRINGS AND CORROSION

Surface-Treatment Process Steps

(U. S. Patent 7,476,791)

1. Prehydrolyze Foundation Layer (e.g., aminosilane) & Optional Top-Coat Solutions

2. Deposit Foundation Layer from dilute solution & flash dry (continuous or batch)

3. Deposit optional top-coat from dilute solution & flash dry (continuous or batch)

4. Bake/Cure

Critical Process Parameters:
- Hydrolysis
- Solution concentrations
- Net deposition mass
- Cure t & T

©2009 A. A. Parker – Page 7; www.aaparkerconsulting.com

A. A. Parker Consulting, LLC
Surface FTIR (ATR) studies show that the deposition of thick films favor the formation of amine salts, whereas the deposition of thin films favor the formation of coordination complexes.

Dynamic Mechanical Analysis (DMA) studies show that thick films are thermally and mechanically unstable, while thin films maintain their mechanical and acoustic integrity (i.e., they are durable).

Sound Enhancement - Acoustic studies reveal that the free-vibration decay rate is actually decreased in the presence of surface treatment (they vibrate for longer times).
FTIR data provide evidence for the existence of chelated amines near the metal interface – this is the desirable bonding condition.
Improving Musical Instrument String Longevity with Organosilanes

**AAPS treated Ti-core strings after 21 days in Brine Solution**

- High levels of AAPS accelerate corrosion
- Low levels provide excellent corrosion protection

**Solution Concentrations**

- 6.4%
- 0.2%
- No treatment
- 0.19%
- 0.006%

**Mass of treatment (% of total string mass)**

- 7.8x10^{-3} moles/m^2
- 2.4x10^{-4} moles/m^2

©2009 A. A. Parker – Page 10; www.aaparkerconsulting.com
Steel-core Strings in Brine Solution

Differences start to appear within hours of exposure
Typical difference between non-treated Ti and steel after 24 hours in NaCl solution

Trends among steel-core strings can be seen within only a few hours, whereas trends among titanium-core strings take several days to appear.
FTIR Surface Spectra (SATR)

High levels of AAPS → protonated amines → accelerated corrosion
Low levels of AAPS → chelated amines → corrosion protection

- N-H str. free or coordinated amine (peak E*) 3400 cm\(^{-1}\)
- Protonated N-H def. (peak C) 1580 cm\(^{-1}\)
- N-H and NH\(_3^+\) stretch (peak B) 3250 cm\(^{-1}\)
- N-H def. free or coordinated amine (peak D*) 1620 cm\(^{-1}\)
- Si-O-Si asym. str. 1100 cm\(^{-1}\)
Resonant Mode DMA

Phosphor Bronze Wound Steel Core "A" Strings with and without AAPS Treatment

- **0.2% AAPS Solution**
  - ACOUSTICALLY BRIGHT
- **6.4% AAPS Solution**
  - ACOUSTICALLY "DEAD"
- **No Treatment**

**Graph Details:**
- Frequency (Hz)
- Time (minutes)
- Length = 21 mm; oscillation amplitude = 0.8 mm

©2009 A. A. Parker – Page 14; www.aaparkerconsulting.com
Resonant Mode DMA - EFFECT OF THERMAL HISTORY
Phosphor Bronze Wound Steel Core "A" Strings with and without AAPS Treatment

- Steel "A" Control
- Steel "A" Control (after 150°C)
- Steel "A" 0.2%
- Steel "A" 0.2% (after 150°C)
- Steel "A" 6.4%
- Steel "A" 6.4% (after 150°C)

DMA
Resonant mode
5°C/min to 150°C
Universal V3.8B TA Instruments

Improving Musical Instrument String Longevity with Organosilanes

©2009 A. A. Parker – Page 15; www.aaparkerconsulting.com
500g weight was tied & suspended from the mid-point of an A-string (tuned to 110 Hz) – sensitive to the fundamental tone

The weight was released to impart vibration

Sound pressure measurements were made after several vocal takes for “We Need Love”

Data were collected (recorded) at a 44.1 kHz sample rate (24 bit depth)
String Vibration

n = 1, 110 Hz (A)
n = 2, 220 Hz (A’)
n = 3, 330 Hz (E)
n = 4, 440 Hz (A’’); n = 5, 550 Hz (C^#); n = 6, 660 Hz (E’);
n = 7, 770 Hz (G^b); n = 8, 880 Hz (A’’’)

Improving Musical Instrument String Longevity with Organosilanes

String Vibration: Decay of the Fundamental Tone

Data were analyzed with EQ band pass filters; over the range 107-113 Hz, which corresponds to about 50 cents above and below the target ‘A’ 110 Hz. In musical terms, 50 cents refers to half the distance between a note and its closest semitone neighbor.

Effect of Surface Treatment on Sound Pressure Level Decay at 110 Hz (A-note)
Medium Tension PB-Wound Ti-Core A-String

SPL = A*(exp(-t/tc)-1)

<table>
<thead>
<tr>
<th>Value</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>tc (sec)</td>
<td>18.1</td>
</tr>
<tr>
<td>A</td>
<td>26.7</td>
</tr>
<tr>
<td>Chisq</td>
<td>47.9</td>
</tr>
<tr>
<td>R</td>
<td>0.99</td>
</tr>
</tbody>
</table>

SPL = A*(exp(-t/tc)-1)

<table>
<thead>
<tr>
<th>Value</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>tc (sec)</td>
<td>11.5</td>
</tr>
<tr>
<td>A</td>
<td>24.3</td>
</tr>
<tr>
<td>Chisq</td>
<td>33.6</td>
</tr>
<tr>
<td>R</td>
<td>0.99</td>
</tr>
</tbody>
</table>

©2009 A. A. Parker – Page 19
String Vibration: Decay of the 2\textsuperscript{nd} Harmonic (n=2)

Effect of Surface Treatment on Sound Pressure Level Decay at 220 Hz (A-note)
Medium Tension PB-Wound Ti-Core A-String

©2009 A. A. Parker – Page 20; www.aaparkerconsulting.com
Acoustic Measurements - Advantages & Limitations

Advantages:
• Simplicity – great for testing relative effects of controlled variables (e.g., presence or absence of a surface treatment) - simple plots of sound pressure (dB) vs. time

• EQ filters were used to qualitatively separate the fundamental (110 Hz) and the 2\textsuperscript{nd} harmonic (220 Hz) from other frequencies

Limitations:
• Even-numbered harmonics are suppressed by center-plucking

• Although simple, the EQ filtering technique leads to “bleed-through” of multiple frequencies
Future Work

• Off-center plucking

• Frequency Analyses – more accurate effect of surface treatment on overtone intensities & decay rates

• Effect of aging on vibration properties

• Effect of extended play on vibration properties

• Titanium vs. Steel

• Next album in progress

• Official release of “We Need Love”

www.tonyparkermusic.com
Conclusions

Organosilanes are ubiquitous in product development applications (at least in my developments)

Musical instrument strings can be improved with silane surface treatments - corrosion protection and enhanced acoustic properties

Processing factors are important (e.g., hydrolysis, method of deposition)

Low-concentration ingredients can have an impact on the performance properties of surface treatments
Acknowledgements

Dave “Magic” Mariasy

Calen Bruce

Starlite MacPark (ASCAP), Newtown, PA; SM0810, All Rights Reserved.