Adapting elastically to Martian environment: 
Low Tg elastomer blends for Martian applications

Rafal Anyszka¹,², Norbert Nizel¹, Dariusz M. Bielinski¹, Anke Blume²

¹Lodz University of Technology, Faculty of Chemistry, Institute of Polymer and Dye Technology, Poland,

²University of Twente, Faculty of Engineering Technology, Department of Mechanics of Solids, Surfaces & Systems (MS3), Chair of Elastomer Technology & Engineering, Enschede, The Netherlands
Current solutions

➢ Martian rovers use **aluminum-based wheels** instead of rubber tires

➢ Aluminum exhibits much better resistance to Martian environment than rubber: superior aging resistance = higher wheel reliability

➢ Martian rovers carry **sensitive equipment** that can suffer from intensive vibration during driving

➢ Aluminum exhibits **low flexibility and damping** properties

**Mars Rovers**

Relative Wheel Sizes

- **Aluminum**
- **Spirit & Opportunity**
  - 2004
- **Sojourner**
  - 1997

Manual controlling from Earth: average 20 min signal delay

+ **Fragile equipment** + **Low elasticity**

**Low speed**

---

https://www.reddit.com/r/space/comments/2dj1xb/comparative_wheel_sizes_of_mars_rovers/
https://i.stack.imgur.com/HejZ8.jpg
https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Exploration/ExoMars/Moving_on_Mars
Current solutions

Mars Rovers
Relative Wheel Sizes

Spirit & Opportunity
2004

Sojourner
1997

Curiosity
2012

Aluminum

Manual controlling from Earth:
average 20 min signal delay

Fragile equipment + Low elasticity

Low speed

Perseverance
2020

Aluminum/Titanium alloy
**Speed comparison**

- **Sea Turtle**: 1.8 km/h
- **Sloth**: 0.18 km/h
- **Martian rover**: 0.14 km/h
- **Garden Snail**: 0.047 km/h

(Images of a tortoise, sloth, Mars rover, and garden snail are used to illustrate the speed comparison.)
Curiosity rover wheel damage

- Too low resistance to continuous deformation
  - low elasticity
- Direct contact with sharp/pointy rocks

Rovers' mass

![Graph showing the mass of Sojourner, Opportunity/Spirit, and Curiosity rovers.](https://www.spaceflightinsider.com/missions/solar-system/wheel-treads-break-curiosity-rover/)

- Sojourner: 11.5 kg
- Opportunity/Spirit: 180 kg
- Curiosity: 899 kg

![Image of a damaged Curiosity rover wheel.](https://spacenews.com/mars-rover-curiosity-dealing-with-wheel-damage/)

![Image of a close-up of the metals on a wheel.](https://www.space.com/26472-mars-rover-curiosity-wheel-damage.html)
Self-driving rovers for Martian missions
“…they’ll be moving hundreds of meters per day.”

➢ No need to control from Earth = Maximum speed can be increased
❖ Higher speed will accelerate the fatigue of wheels
❖ Damping properties have to be improved to protect the sensitive equipment

From the beginning of 2019
ESA is testing a self driving software for Martian rovers

Stil on metal wheels…
Self-driving rovers for Martian missions

“...they’ll be moving hundreds of meters per day.”

- No need to control from Earth = Maximum speed can be increased
  - Higher
  - Dampir
  - Better resistance to elastic deformation
  - Worse resistance to Martian environment

From the beginning of 2019 ESA is testing a self driving software for Martian rovers

Still on metal wheels...

https://earthsky.org/space/mars-rovers-self-driving-technology-tested-by-uk
How about high performance vehicles on Mars?

## Comparison of Earth and Mars Environments

<table>
<thead>
<tr>
<th></th>
<th>Earth</th>
<th>Mars</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature range</strong></td>
<td>(-88 °C) – 58 °C</td>
<td>(-140 °C) – 30 °C</td>
</tr>
<tr>
<td><strong>Pressure</strong></td>
<td>101.3 kPa</td>
<td>0.6 kPa</td>
</tr>
<tr>
<td><strong>Radiation</strong></td>
<td>Low – 3.0 mSv/a;</td>
<td>High – 400-500 mSv/a;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>additionally occasional solar proton events</td>
</tr>
<tr>
<td><strong>Atmosphere</strong></td>
<td>21 % oxygen; 78 % nitrogen; 1 % other</td>
<td>96 % carbon dioxide; &lt;2 % argon; &lt;2% nitrogen; &lt;1% other</td>
</tr>
</tbody>
</table>

https://visibleearth.nasa.gov/images/54388/earth-the-blue-marble
https://solarsystem.nasa.gov/planets/mars/in-depth/
https://mars.nasa.gov/all-about-mars/facts/
Rubber flexibility

Glass transition temperature

Glassy state

Rubbery state

https://www.youtube.com/watch?v=mW-FB4L9UA&t=3s
https://omnexus.specialchem.com/polymer-properties/properties/glass-transition-temperature
https://rigid.ink/products/flexible-pla-1-75-mm-0-03-mm-tolerance-filament
Can the rubber flexibility be preserved on Mars?

[Graph showing temperature changes over time for Spirit Sol with temperature levels marked for Winter, Summer, and Maximum and Minimum points.]

- Butadiene rubber (BR)
- Silicone rubber (VMQ)

https://mars.nasa.gov/mer/spotlight/20070612.html
Idea – blending of VMQ & BR

➢ BR as the continuous phase will provide better **mechanical** and **abrasion resistance**

➢ VMQ as the dispersed phase will provide better **low temperature resistance**

➢ But: Silicone rubber exhibits **limited miscibility** with organic rubbers

➢ Application of a compatibilizer is required

SSBR/VMQ (80/20) blends filled with:

(a) reference

(c) 4 phr trimethylolpropane tris(3-mercaptopropionate)

# Improving VMQ compatibility with organic rubber – own study

## Formulation

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>REF [phr]</th>
<th>Coupl [phr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butadiene rubber</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Silicone rubber</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>ZnO</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Stearic acid</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Sulfur</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>CBS</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Trimethylolpropane tris(3-mercaptopropionate)</td>
<td>-</td>
<td>4</td>
</tr>
</tbody>
</table>

## Compounding

**Mixing conditions**

<table>
<thead>
<tr>
<th>Laboratory mixer 50 cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
</tr>
<tr>
<td>Temp. rise</td>
</tr>
<tr>
<td>Time</td>
</tr>
<tr>
<td>Rotor speed</td>
</tr>
</tbody>
</table>

1 phr = 1 part per hundred rubber
Improving VMQ compatibility with organic rubber – own study

DSC and DMA investigation of the glass transition temperature of the blends

In comparison to the pure rubber: „green”
Improving VMQ compatibility with organic rubber – own study

SEM

Coupl

REF

Micromorphology investigation

EDX

Si mapping

Significant improvement in the silicone rubber dispersion
Improving radiation resistance and mechanical properties

➢ Carbon Black (CB) is a free-radical scavenger that improves the radiation resistance of rubber

➢ CB also improves the mechanical properties of rubber
## Blending VMQ and BR with carbon black

### Formulation

<table>
<thead>
<tr>
<th>Component</th>
<th>Amount [phr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>BR</td>
<td>80</td>
</tr>
<tr>
<td>VMQ</td>
<td>20</td>
</tr>
<tr>
<td>ZnO</td>
<td>3</td>
</tr>
<tr>
<td>Stearic acid</td>
<td>3</td>
</tr>
<tr>
<td>Sulfur</td>
<td>1.2</td>
</tr>
<tr>
<td>CBS</td>
<td>1.6</td>
</tr>
<tr>
<td>Carbon Black N774</td>
<td>25 / 37.5 / 50</td>
</tr>
<tr>
<td>6PPD</td>
<td>2</td>
</tr>
</tbody>
</table>

### Compounding

<table>
<thead>
<tr>
<th>Time</th>
<th>Action</th>
<th>Rotor speed [rpm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:00</td>
<td>Add rubber, zinc oxide, stearic acid, 6PPD, carbon black</td>
<td>20</td>
</tr>
<tr>
<td>3:00</td>
<td>Increase rotor speed</td>
<td>60</td>
</tr>
<tr>
<td>5:00</td>
<td>Decrease rotor speed, add CBS, sulfur</td>
<td>20</td>
</tr>
<tr>
<td>6:30</td>
<td>Increase rotor speed</td>
<td>60</td>
</tr>
<tr>
<td>7:30</td>
<td>Stop mixing</td>
<td>0</td>
</tr>
</tbody>
</table>

---

Blending VMQ with BR with carbon black

Tensile properties at -40 °C

Hardness, °ShA

Tear resistance at -40 °C, N/mm
Summary

➢ Increase of Martian rover’s mass + self driving software = new wheel design of higher fatigue and damping properties that withstand higher rover speed

➢ Rubber can be a promising material for the new Martian rovers’ wheels if its radiation resistance and low temperature flexibility are improved

➢ Silicone & butadiene rubber blends might be suitable

➢ Mechanical properties of the blends are improved by addition of carbon black.

➢ Compatibility of the silicone & butadiene rubber can be improved by addition of trimethylopropane tris(3-mercaptopropionate)
Stay tuned!

Marie Skłodowska Curie Action: Global Fellowship. Grant No. 101025756: “Rubber & Elastomer Development for MArtian enviRonmental applications (RED 4 MARS)”

Starting – 1st of March 2022
Thank you for your kind attention!