Compounding and Manufacturing Elastomers for Nuclear Applications

Polymers in nuclear applications 2019
Andrew Douglas FIMMM
Our Heritage
James Walker
1840 - 1913

Early trade marks and signage from 1889
Lion Works, Woking 1936
and still where company head offices are today
Supplying the Royal Air Force among others during the Second World War

Hand-making special copper joints, c.1950
The Cockermouth Factory completed in 1969...

...and opened by the Prime Minister, Harold Wilson in February 1970
James Walker Overview

- 2000 employees / £200m turnover
- Established 1882
- 16 manufacturing sites
- 35 sales / support offices

Centres of Excellence
Materials Technology and Manufacture

- Advanced Engineered Plastics
- Precision Machined Metals
- High Performance Elastomers
- Innovative Bolting Technology
- Vibration Attenuation

[Map showing locations around the world with markers for each centre of excellence]
What is an Elastomer?
The concept of polymers
Polymer structure
Polymer structure with crosslinks
The history of natural rubber
The development of synthetic rubbers and compounding
Designing synthetic polymers…

**Monomers & Polymers**

- Monomers
- Polymer of three monomers
- Polymer of five monomers

**Attributes of monomer ‘building blocks’**

- **Strength** of bonds within molecules and between them
- **Highly polar** gives resistance to swelling by oils/fuels
- **Flexibility** at low temperatures
How long will it last?

‘All of the disputed territories contain valuable minerals, and some of them yield important vegetable products such as rubber which in colder climates it is necessary to synthesize by comparatively expensive methods’

Nineteen Eighty-Four, George Orwell, first published June 1949

 Synthetic elastomers haven’t actually been around for that long so

100 year life predictions come with caveats...
GENERAL ELASTOMER CLASSIFICATION

- General Purpose
- Low oil resistance
- General Purpose Oil Resistant
- High Performance

Materials:
- Chloroprene
- Ethylene-Propylene
- Fluorocarbon
- Silicone
- Acrylic
- Polyurethane
- Nitrile
- HNBR
- Aflas®
Natural Rubber (NR)

Advantages: High resilience; high tensile/tear; good abrasion resistance; low cost.

Disadvantages: Poor oil resistance; poor weathering resistance. Reversion.

Typical temperature range: -50°C to +100°C
Ethylene-Propylene Rubber (EPM, EPDM)

Dipolymer of ethylene and propylene (EPM), or Termonomer of ethylene-propylene with a diene monomer

Advantages: Excellent ozone/weathering resistance. Excellent radiation, hot water and steam resistance (peroxide grades); good resistance to inorganic and polar organic chemicals.

Disadvantages: Low resistance to hydrocarbons.

Typical temperature range: -45°C to +150°C (-49°F to +300°F).
Advantages: Good weather and ozone resistance; good mechanicals; resistance to many Freons; some oil resistance; low cost.

Disadvantages: Only moderate oil resistance; limited temperature resistance.

Typical temperature range: -40°C to +120°C ( -40°F to +250°F)
Nitrile Rubber (NBR)

Acrylonitrile-butadiene

Typical temperature range: -50°C to +120°C (dependent on ACN content!)
Hydrogenated Nitrile Rubber (HNBR/HSN)

Made from NBR by hydrogenation reaction

**Typical temperature range:** -40°C to +160°C (dependent on ACN content!)
**Fluoroelastomers (FKM/FPM)**

*Eg., ‘Viton®’, ‘Fluorel®’, ‘Tecnoflon®*, DAI-El™*

Vinylidene fluoride, VDF (VF₂)  
Hexafluoropropylene, HFP  
Tetrafluoroethylene, TFE  
Cure site monomer, CSM

**Dipolymers**, VDF and HFP, ~66%F (*A* Types)  
**Terpolymers**, VDF, HFP, TFE (CSM) ~68%F to ~70%F FKM (*B* types at 68%F and *F*types at 70%F).

**Typical temperature range:**  -45°C to +200°C
Advantages: Excellent ozone/weathering resistance; good heat resistance; excellent resistance to steam and radiation; good overall chemical resistance.

Disadvantages: High compression set; high Tg; poor resistance to aromatics

Typical temperature range: 0°C to +200°C
What goes in to an elastomer?
<table>
<thead>
<tr>
<th></th>
<th>COMPOUND INGREDIENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>POLYMERS</td>
</tr>
<tr>
<td>2</td>
<td>CURATIVES</td>
</tr>
<tr>
<td>3</td>
<td>ACCELERATORS</td>
</tr>
<tr>
<td>4</td>
<td>ACTIVATORS</td>
</tr>
<tr>
<td>5</td>
<td>RETARDERS</td>
</tr>
<tr>
<td>6</td>
<td>CO-AGENTS</td>
</tr>
<tr>
<td>7</td>
<td>FILLERS</td>
</tr>
<tr>
<td>8</td>
<td>PLASTICISERS</td>
</tr>
<tr>
<td>9</td>
<td>EXTENDERS</td>
</tr>
<tr>
<td>10</td>
<td>PROTECTANTS</td>
</tr>
<tr>
<td>11</td>
<td>BONDING PROMOTERS</td>
</tr>
<tr>
<td>12</td>
<td>PROCESS AIDS</td>
</tr>
<tr>
<td>13</td>
<td>TACKIFIERS</td>
</tr>
<tr>
<td>14</td>
<td>DESICCANTS</td>
</tr>
<tr>
<td>15</td>
<td>PIGMENTS</td>
</tr>
<tr>
<td>16</td>
<td>BLOWING AGENTS</td>
</tr>
<tr>
<td>17</td>
<td>PEPTISERS</td>
</tr>
<tr>
<td>18</td>
<td>FLAME RETARDANTS</td>
</tr>
<tr>
<td>19</td>
<td>ODOURANTS</td>
</tr>
<tr>
<td>20</td>
<td>COUPLING AGENTS</td>
</tr>
<tr>
<td></td>
<td>High Quality</td>
</tr>
<tr>
<td>------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>34% ACN NBR</td>
<td>100</td>
</tr>
<tr>
<td>Zinc oxide</td>
<td>5</td>
</tr>
<tr>
<td>Stearic acid</td>
<td>1</td>
</tr>
<tr>
<td>Sulphur</td>
<td>1</td>
</tr>
<tr>
<td>Accelerators</td>
<td>4</td>
</tr>
<tr>
<td>Ester plasticiser</td>
<td>7</td>
</tr>
<tr>
<td>AO₂ / AO₃</td>
<td>2</td>
</tr>
<tr>
<td>Carbon black N550</td>
<td>70</td>
</tr>
<tr>
<td>Oil extender</td>
<td>-</td>
</tr>
<tr>
<td>Chalk Dust</td>
<td>-</td>
</tr>
<tr>
<td>Talcum Powder</td>
<td>-</td>
</tr>
<tr>
<td>White filler</td>
<td>-</td>
</tr>
<tr>
<td>Wax</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total PHR</strong></td>
<td><strong>190</strong></td>
</tr>
<tr>
<td></td>
<td>High Quality</td>
</tr>
<tr>
<td>---------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Cure</td>
<td>6 minutes at 180°C</td>
</tr>
<tr>
<td>Hardness (IRHD)</td>
<td>78</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>19.3</td>
</tr>
<tr>
<td>E @ B (%)</td>
<td>300</td>
</tr>
<tr>
<td>Modulus at 25% strain (MPa)</td>
<td>1.3</td>
</tr>
<tr>
<td>Modulus at 50% strain (MPa)</td>
<td>2.2</td>
</tr>
<tr>
<td>Modulus at 100% strain (MPa)</td>
<td>4.8</td>
</tr>
<tr>
<td>Tear strength (N/mm)</td>
<td>42</td>
</tr>
<tr>
<td>Compression Set, 24hr @ 70°C (%)</td>
<td>7</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>1.2</td>
</tr>
</tbody>
</table>
One piece of rubber looks pretty much another....
Elastomer behaviour at low temperatures

- Decrease in energy
- Polymer chains lose flexibility
- ‘Leathery phase’ before taking on the properties of glass
- Properties vary depending on the polymer type/formulation
Elastomer behaviour at high temperatures

- Long-term resistance influenced by strength of bonds between atoms
- Stronger bonds permit higher operating temperatures
- Mechanical properties will reduce
Swelling

- Elastomer will absorb the contact media and swell
- Physical effect, which is to some extent reversible

Chemical Attack

- Polymer chain is altered / attacked by the contact media
- Irreversible

Elastomer behaviour in contact media

Can occur at the same time
Mechanico-oxidative fatigue

Heat and oxidation

Crosslink reversion

Sunlight crazing

Abrasion

Compression set at high temperature

Ozone cracking
Environmental Qualification

Fixed formulations – fantastic

But…

Legacy materials – availability of raw ingredients
Shieldseal® 661, 663 and 664 Elastomers

Radiation testing carried out by Wood Group

- Exposure to gamma radiation
- 1kGyhr⁻¹ up to 1000 kGy
- Followed by further 600 kGy
- Aged and unaged samples
- Intended to replicate LOCA – broadly based on IEEE 383 / IEC 60780 standards
Accelerated Thermal Ageing
Potential impact of variations in Activation Energy

Victoria Smith Wood Group EQSA Seminar Sept 2019
Thank you!
This presentation is provided on the basis that it is a general guide and for information purposes only; it is neither extensive nor comprehensive and its content does not in any way provide you with any qualification to carry on any trade or services.

James Walker Sealing Products and Services Limited or any other company within the same group of companies cannot accept any responsibility for any liabilities of any kind incurred in reliance on this presentation.

Copyright in the whole and every part of this presentation belongs to, or is licensed by its owner to, James Walker Sealing Products and Services Limited (the owner) and may not be used, sold, licensed, transferred, copied or reproduced in whole or in part in any manner or form or in or on any media to any person without the prior written consent of the owner. Full acknowledgement of the owner and source made must be given.

Warning: Carrying out any unauthorised act in relation to copyright work may result in both a civil claim for damages and criminal prosecution.
Important Notice - Product & Material Claims

Product and material information given in this presentation is given in good faith and represents the results of specific individual tests carried out by James Walker or third parties in accordance with the methodologies described in this presentation or supplementary publication supplied, performed in a laboratory. No representation or warranty is given in relation to such information.

Values and/or operating limits given in this presentation are not an indication that these values and/or operating limits can be applied simultaneously. While such results may comprise useful additional information and are industry standard tests, they are no substitute for conducting (or procuring from James Walker) your own tests and engineering analysis and satisfying yourself as to the suitability of the product you select.

Please also note that a product tested in accordance with the published methodology may not perform to such values in application and/or under different test conditions or methodologies for a variety of reasons, including but not limited to the environment in which it is used/tested or which passes through it or otherwise affects the product, or due to the handling, storage or installation, or due to the effect of housing or other parts. Our personnel will be happy to discuss any historical examples we have of a product having been previously used in a particular application.