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Claigan PFAS Submission #4

Comparison of Alternatives

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1. Summary

This report is submission #4 of 5 by Claigan Environmental Inc. (Claigan) on behalf of the EU PFAS Restriction Submission Project ("PFAS Submission Project"). The PFAS submission project is made up of dozens of companies in a wide range of industries (consumer, professional, industrial, medical, oil and gas, laboratory equipment, textiles, electronic components, and retail sales).

The PFAS Submission Project is focused primarily on the needs of complex products (articles). Claigan is both a restricted materials consultancy and high volume restricted materials testing laboratory. Each of the PFAS Submission Project submissions is based on contributions from all major sectors of industry and 2023 PFAS testing data of complex products.

This report (#4) is a detailed review of the pro's and con's of each major PFAS material and their potential substitutes.

Note - the forever chemicals data is based on testing data from 2022 and 2023 on representative materials.

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2. Comparison Chart

Comparison	PTFE	PEEK	Silicone	Poly urethane	PFA	Irradiated PTFE	ePTFE	Fluoro acrylates	FKM	FFKM	PVDF	Nitrile Rubber	EPDM	Stainless steel	Fluoro silicone
Low Friction	Excellent	Decent	Decent	Poor	Decent	Excellent	Excellent	Excellent	Poor	Poor	Decent	Poor	Poor	Poor	Excellent
Chemical Resistance	Excellent	Decent	Decent	Poor	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Decent	Decent	Poor	Decent
Water Resistance	Excellent	Excellent	Decent	Decent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Oil Resistance	Excellent	Excellent	Poor	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Poor	Excellent	Excellent
Temperature Resistance	Excellent	Excellent	Excellent	Poor	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Decent	Decent	Decent	Excellent	Excellent
Flexibility	Decent	Poor	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Poor	Excellent	Excellent	Poor	Excellent
Forever Chemicals (initial)	Excellent	Excellent	Poor	Excellent	Decent	Decent	Decent	Decent	Decent	Decent	Excellent	Excellent	Excellent	Excellent	Poor
Forever Chemicals (over time)	Excellent	Excellent	Decent	Excellent	Decent	Excellent	Excellent	Decent	Excellent	Decent	Excellent	Excellent	Excellent	Excellent	Decent
Bio-compatibility	Excellent	Excellent	Decent	Decent	Excellent	Excellent	Excellent	Decent	Decent	Decent	Excellent	Decent	Decent	Excellent	Decent

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Insulation	Excellent	Decent	Decent	Decent	Excellent	Excellent	Excellent	Excellent	Poor	Poor	Poor	Decent	Decent	Poor	Excellent
Radiation Resistance	Poor	Excellent	Poor	Decent	Poor	Poor	Poor	Poor	Poor	Poor	Decent	Poor	Decent	Excellent	Poor

3. Definitions

3.1. Low Friction

3.1.1. Excellent - low coefficient of static friction. Nearly frictionless.
3.1.2. Decent - lower coefficient of static friction but has some friction in use.
3.1.3. Poor - high coefficient of static friction. Displays strong friction during use and not suitable for applications requiring low friction.

3.2. Chemical Resistance

3.2.1. Excellent - excellent resistance to acids and bases. No discernible effect.
3.2.2. Decent - resistant to acids and bases. But does exhibit some degradation. Should not be in extended contact or subject to high concentrations of acids or bases.
3.2.3. Poor - not resistant to acids, and/or bases..
3.2.4. Note - the resistance to acids or bases may not be uniformly excellent, decent, or poor for a material. The rating reflects its general potential applications of the material.

3.3. Water Resistance

3.3.1. Excellent - Hydrophobic. Impermeable to water even as a coating.
3.3.2. Decent - Resistant to water, but not completely hydrophobic or water proof..
3.3.3. Poor - Permeable by water.

3.4. Oil Resistance

3.4.1. Excellent - excellent resistance to oils. No discernible effect.
3.4.2. Decent - resistant to oil. But does exhibit some degradation or permeability. Should not be in extended contact with oils.
3.4.3. Poor - not resistant to oil.

3.5. Temperature Resistance

3.5.1. Excellent - Can withstand temperatures above 150C
3.5.2. Decent - Can withstand temperatures above 100C
3.5.3. Poor - Impacted by temperature above 100C

3.6. Flexibility

3.6.1. Excellent - Exhibits good flexibility and useful in most applications requiring flexibility.
3.6.2. Decent - Not completely rigid, and exhibits some flexibility.
3.6.3. Poor - Rigid. Not suitable for applications requiring flexibility.

3.7. Forever Chemicals (initial)

3.7.1. Excellent - Contains no substances with an EU harmonized classification of vPvB or PBT after manufacturing.

3.7.2. Decent - Contains trace (<1 ppm) of substances with an EU harmonized classification of vPvB or PBT after manufacturing

3.7.3. Poor - Contains (> 1ppm) of substances with an EU harmonized classification of vPvB or PBT after manufacturing

3.8. Forever Chemicals (over time)

3.8.1. Excellent - Does not degrade into substances with an EU harmonized classification of vPvB or PBT.

3.8.2. Decent - Degrades lightly (<1 ppm) of substances with an EU harmonized classification of vPvB or PBT over time.

3.8.3. Poor - Degrades into (> 1ppm) of substances with an EU harmonized classification of vPvB or PBT over time.

3.9. Biocompatibility

3.9.1. Excellent - Passes EU MDR biocompatibility testing and does not normally require toxicological justification.

3.9.2. Decent - Passes EU <DDR biocompatibility testing but often requires toxicological justification.

3.9.3. Poor - Does not generally pass EU MDR biocompatibility testing or requires significant justification.

3.10. Low dielectric constant

3.10.1. Excellent - Low dielectric constant. Suitable for most insulation or electronics purposes.

3.10.2. Decent - Medium dielectric constant. Suitable for some insulation or electronics purposes.

3.10.3. Poor - High dielectric constant. Not normally suitable as an insulating material in electronics.

3.11. Radiation Resistance

3.11.1. Excellent - Excellent resistance to gamma and e-beam radiation. Does not exhibit degradation.

3.11.2. Decent - Decent resistance to gamma and e-beam radiation. Exhibits degradation with repeat or high dosage exposure.

3.11.3. Poor - Degrades in gamma or e-beam radiation.

4. Polytetrafluoroethylene (PTFE)

Representative CAS # - 9002-84-0

4.1. Summary

4.1.1. PTFE is the most common fluoropolymer with a wide range of applications. This listing is for the unirradiated and unexpanded PTFE polymer. Irradiated PTFE and ePTFE have separate summaries in this document even though they share the same CAS number. The additional processing of irradiation or expansion changes the chemical characteristics of PTFE sufficiently that separate listings were necessary.

4.2. Low Friction

4.2.1. PTFE has a very low static friction coefficient.

4.3. Chemical Resistance

4.3.1. PTFE is highly resistant to a wide range of acids, including hydrochloric acid, sulfuric acid, and nitric acid.

4.3.2. PTFE is highly resistant to a wide range of bases, including sodium hydroxide and potassium hydroxide. This makes it an ideal material for use in applications that involve the handling of basic liquids or gases, such as in the chemical and pharmaceutical industries.

4.4. Water Resistance

4.4.1. PTFE is strongly hydrophobic (water shedding). Water cannot readily wet out the surfaces

4.5. Oil Resistance

4.5.1. PTFE is oleophobic (oil shedding) and strongly resistant to oils and stains.

4.6. Temperature Resistance

4.6.1. PTFE has excellent temperature resistance with chemical inertness and temperature resistance ranging from -200 to 260 °C

4.7. Flexibility

4.7.1. PTFE is only moderately flexible and requires irradiation or expansion (ePTFE) to be fully flexible.

4.8. Forever Chemicals (initial)

4.8.1. Unirradiated and unexpanded PTFE does not contain any PFOA or PFOS family of chemicals. PFOA related substances may have been used decades ago for the manufacture of PTFE, but testing of hundreds of PTFE parts by Claigan has not shown any PFOA or PFOS related chemicals in unirradiated and unexpanded PTFE.

4.9. Forever Chemicals (over time)

4.9.1. PTFE does not degrade into forever chemicals such as PFOA or PFOS. PTFE does not have the ether bond (C-O-C) that leads to degradation into PFOA related chemicals that can occur in other fluoropolymers (such as fluoroacrylate coatings or PFA polymers).

4.10. Biocompatibility

4.10.1. PTFE is highly biocompatible and does not normally release any substance that would require toxicological evaluation for invasive or implantable medical devices.

4.11. Low dielectric constant

4.11.1. PTFE has the best electrical properties of any plastic material with a low dielectric constant that does not change with temperature or frequency. This property makes PTFE an excellent insulator for electronic purposes.

4.12. Radiation Resistance

4.12.1. PTFE is not suitable for gamma radiation or e-beam radiation exposure. Radiation exposure causes the polymer chains to break down, significantly changing the properties (and chemical composition) of the material.

4.12.2. Irradiation PTFE (a separate listing in this document) is PTFE irradiated in a controlled manner to reduce the durometer (‘rubberize’) of the PTFE polymer. Beyond the changes in physical characteristics, irradiation of PTFE creates small concentrations of the PFOA family of various lengths.

4.13. Conclusion - PTFE

4.13.1. Standard PTFE (unirradiated and unexpanded) is one of the safest polymers available with no forever chemicals and excellent biocompatibility.

5. Polyether ether ketone (PEEK)

CAS # - 29658-26-2

5.1. Summary

5.1.1. Polyether ether ketone (PEEK) is a colourless organic thermoplastic polymer in the polyaryletherketone (PAEK) family.

5.1.2. PEEK is not a PFAS substance, and is included in this report as a potential substitute.

5.2. Low Friction

5.2.1. PEEK's coefficient of static friction is low but twice as high as PTFE.

5.3. Chemical Resistance

5.3.1. PEEK is resistant to a wide range of acids but does decompose at higher concentrations of nitric and sulfuric acids.

5.3.2. PEEK is highly resistant to a wide range of bases, including sodium hydroxide and potassium hydroxide.

5.4. Water Resistance

5.4.1. PEEK is strongly hydrophobic (water shedding). Water cannot readily wet out the surfaces

5.5. Oil Resistance

5.5.1. PEEK is oleophobic (oil shedding) and strongly resistant to oils and stains.

5.6. Temperature Resistance

5.6.1. PEEK has excellent thermal range and can be used continuously up to 250 °C

5.7. Flexibility

5.7.1. PEEK is very rigid and not suitable for flexible applications.

5.8. Forever Chemicals (initial)

5.8.1. PEEK does not normally contain any substances with an EU harmonized classification of vPvB or PBT after manufacturing.

5.9. Forever Chemicals (over time)

5.9.1. PEEK does not normally degrade into substances with an EU harmonized classification of vPvB or PBT.

5.10. Biocompatibility

5.10.1. PEEK is highly biocompatible and does not normally release any substance that would require toxicological evaluation for invasive or implantable medical devices.

5.11. Low dielectric constant

5.11.1. PEEK has a decently low dielectric constant but not sufficiently low for many electrical insulation applications.

5.12. Radiation Resistance

5.12.1. PEEK shows good resistance to gamma and e-beam radiation.

5.13. Conclusion - PEEK

5.13.1. PEEK has excellent biocompatibility, but its moderate friction and dielectric constant with poor flexibility makes PEEK unsuitable as a substitute for most fluoropolymer applications.

6. Silicone Rubber

CAS # - 63394-02-5

6.1. Summary

6.1.1. Silicone rubber (polysiloxane) is an elastomer (rubber-like material) composed of silicone. Silicone rubber has many different formulations. This listing is for the standard cured (vulcanized) form.

6.1.2. Silicone rubber is not a PFAS substance, and is included in this report as a potential substitute.

6.2. Low Friction

6.2.1. Silicone rubber has a moderate coefficient of static friction and is not generally useful in situations requiring very low friction.

6.3. Chemical Resistance

6.3.1. Silicone rubber is highly resistant to a wide range of acids, including hydrochloric acid, sulfuric acid, and nitric acid.

6.3.2. Silicone rubber is highly resistant to a wide range of bases, including sodium hydroxide and potassium hydroxide.

6.4. Water Resistance

6.4.1. Silicone rubber is water resistant but is not completely waterproof. Silicone rubber is not suitable for water proof coatings that have to weather intense water conditions.

6.5. Oil Resistance

6.5.1. Silicone rubber is not oil resistant and is easily penetrated by oils. Silicone rubber retains stains and smells, and is not suitable for situations requiring oil resistance.

6.6. Temperature Resistance

6.6.1. Silicone rubber has excellent thermal range and can be used continuously up to 300 °C

6.7. Flexibility

6.7.1. Silicone rubber is very flexible and is suitable for applications requiring significant flexibility.

6.8. Forever Chemicals (initial)

6.8.1. Silicon rubber commonly has high concentrations of classified D4, D5, and D6 chemicals (EU classified PBT substances). Claigan testing of hundreds of samples from 2021 to 2023 showed a median D6 concentration of 300 ppm in silicone rubber. This concentration is 1,000X higher concentration of forever chemicals than irradiated PTFE (and far worse than standard PTFE which does not contain forever chemicals).

6.8.2. D4, D5, and D6 are scheduled for restriction under the UN Stockholm Convention on Persistent Organic Pollutant, making silicone a poor potential replacement for fluoropolymers.

6.9. Forever Chemicals (over time)

6.9.1. Silicon rubber does degrade further over time (slowly) in D4, D5, and D6 siloxanes (forever chemicals).

6.10. Biocompatibility

6.10.1. Silicone rubber has reasonable biocompatibility but silicone rubber does generally release substances that require toxicological evaluation for invasive or implantable medical devices. It is common for medical devices using silicone rubber parts to have to conduct toxicological risk assessment of the D6 (and similar siloxanes) that are released from the silicone rubber parts.

6.11. Low dielectric constant

6.11.1. Silicone rubber has a decently low dielectric constant but not sufficiently low for many electrical insulation applications.

6.12. Radiation Resistance

6.12.1. Silicone rubber has poor resistance to gamma and e-beam radiation, and degrades significantly in the presence of radiation.

6.13. Conclusion - Silicone rubber

6.13.1. Silicone rubber is a poor substitute for fluoropolymers in many applications due to its only moderate water resistance, and poor oil resistance. With silicone rubber’s high concentration of forever chemicals and the upcoming listing of the D4, D5, and D6 siloxanes under the UN Stockholm Persistent Organic Pollutant regulation, silicone rubber is not generally considered a viable long term alternative for fluoropolymers.

7. Polyurethane

CAS # - 9009-54-5

7.1. Summary

7.1.1. Polyurethane (PUR or PU) refers to a class of polymers composed of organic units joined by carbamate (urethane) links. In contrast to other common polymers such as polyethylene and polystyrene, polyurethane is produced from a wide range of starting materials.

7.1.2. Polyurethane is not a PFAS substance, and is included in this report as a potential substitute.

7.2. Low Friction

7.2.1. Polyurethane has a high coefficient of static friction and is not useful in situations requiring low friction.

7.3. Chemical Resistance

7.3.1. Polyurethane is not resistant to a wide range of acids, including hydrochloric acid, sulfuric acid, and nitric acid. Polyurethane generally degrades in the presence of moderate acids.

7.3.2. Polyurethane is not resistant to a wide range of bases, including sodium hydroxide and potassium hydroxide. Polyurethane generally degrades in the presence of moderate bases.

7.4. Water Resistance

7.4.1. Polyurethane is water resistant but is not completely waterproof. Polyurethane is not suitable for water proof coatings that have to weather intense water conditions.

7.5. Oil Resistance

7.5.1. Polyurethane is a range of materials and highly oil resistant versions are available. Common polyurethane types would be suitable for oil resistant applications.

7.6. Temperature Resistance

7.6.1. General blends of polyurethane are only usable up to 93C. Specialized high performance grades can reach 150C, but these are not as common.

7.7. Flexibility

7.7.1. Polyurethane is very flexible and is suitable for applications requiring significant flexibility.

7.8. Forever Chemicals (initial)

7.8.1. Polyurethane does not normally contain any substances with an EU harmonized classification of vPvB or PBT after manufacturing.

7.9. Forever Chemicals (over time)

7.9.1. Polyurethane does not normally degrade into substances with an EU harmonized classification of vPvB or PBT.

7.10. Biocompatibility

7.10.1. Polyurethane has reasonable biocompatibility but polyurethane does generally release substances that require toxicological evaluation for invasive or implantable medical devices. It is common for medical devices using polyurethane rubber parts to have to conduct toxicological risk assessment of the isocyanates that are released from the polyurethane parts.

7.11. Low dielectric constant

7.11.1. Polyurethane has a decently low dielectric constant but not sufficiently low for many electrical insulation applications.

7.12. Radiation Resistance

7.12.1. Polyurethane has one of the best resistances to gamma and e-beam radiation among plastics. Polyurethane does degrade at higher radiation doses, but it can reasonably tolerate lower radiation doses.

7.13. Conclusion - Polyurethane

7.13.1. Polyurethane may be able to replace fluoropolymers in some general / low tolerance applications. But in general, polyurethane does not have the performance characteristics needed for most fluoropolymer applications in particular applications related to low friction, acid resistance, or temperature.

8. Perfluoroalkoxy alkane (PFA)

CAS # - 26655-00-5

8.1. Summary

8.1.1. Perfluoroalkoxy alkanes (PFA) are fluoropolymers. They are copolymers of tetrafluoroethylene (C_2F_4) and perfluoroethers ($C_2F_3OR_f$, where R_f is a perfluorinated group such as trifluoromethyl (CF_3) or longer). The properties of these polymers are similar to those of polytetrafluoroethylene (PTFE). Compared to PTFE, PFA has better flexibility, equivalent low friction, and higher chemical resistance.

8.1.2. PFA is commonly used in applications where superior flexibility is needed compared to PTFE such as internal wiring in dense electronics or in medical devices.

8.2. Low Friction

8.2.1. PFA has a very low static friction coefficient.

8.3. Chemical Resistance

8.3.1. PFA is highly resistant to a wide range of acids, including hydrochloric acid, sulfuric acid, and nitric acid.

8.3.2. PFA is highly resistant to a wide range of bases, including sodium hydroxide and potassium hydroxide. This makes it an ideal material for use in applications that involve the handling of basic liquids or gases, such as in the chemical and pharmaceutical industries.

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8.4. Water Resistance

8.4.1. PFA is strongly hydrophobic (water shedding). Water cannot readily wet out the surfaces

8.5. Oil Resistance

8.5.1. PFA is oleophobic (oil shedding) and strongly resistant to oils and stains.

8.6. Temperature Resistance

8.6.1. PFA has excellent temperature resistance with chemical inertness and temperature resistance ranging from -200 to 260 °C

8.7. Flexibility

8.7.1. PFA is very flexible and is often used instead of PTFE in applications requiring superior flexibility.

8.8. Forever Chemicals (initial)

8.8.1. The ether bond in PFA commonly breaks during manufacturing (due to the low energy of bond dissociation of the ether bond), releasing random lengths of PFAS changes that become the range of C2 to C14 perfluorocarboxylates (ie. the PFOA family). PFA normally has 100 to 300 ppb of each length of the PFOA family.

8.9. Forever Chemicals (over time)

8.9.1. PFA does degrade further overtime into additional lengths of perfluorocarboxylates (PFOA family) due to the cleavage of the remaining ether (C-O-C) bonds.

8.10. Biocompatibility

8.10.1. PFA is highly biocompatible but it does release a small amount of the perfluorocarboxylates (PFOA family). PFA's PFOA concentration is not normally high enough to require toxicological risk assessment, but PFOA has a measurable presence in biocompatibility extracts from PFA containing medical devices.

8.11. Low dielectric constant

8.11.1. PFA has electrical properties similar to PTFE with a low dielectric constant that does not change with temperature or frequency. This property makes PFA an excellent insulator for electronic purposes.

8.12. Radiation Resistance

8.12.1. PFA is not suitable for gamma radiation or e-beam radiation exposure. Radiation exposure causes the polymer chains to break down, significantly changing the properties (and chemical composition) of the material and produces additional perfluorocarboxylates (PFOA family).

8.13. Conclusion - PFA

8.13.1. PFA contains low concentrations of forever chemicals (PFOA family), but is needed for applications requiring superior flexibility, temperature resistance, flexibility, and low friction such as dense electronics or medical devices.

9. Irradiated Polytetrafluoroethylene (PTFE)

CAS # - 9002-84-0 (Irradiated - Same at PTFE)

9.1. Summary

9.1.1. PTFE in its normal state is fairly rigid. For use in situations requiring flexibility, PTFE is often irradiated with either gamma or e-beam radiation. The radiation fractures the long polymer chains. Most of the chains reconnect randomly with other fractured chains (called crosslinking) to create a rubberized form of PTFE.

9.1.2. However, some chain fractures react with oxygen and form different lengths of perfluorocarboxylates (PFOA family).

9.1.3. Applications for irradiated PTFE include heat shrinkable tubing and plumber's (pool) tape. PTFE tape in medical devices is commonly made from irradiated PTFE.

9.2. Low Friction

9.2.1. Irradiated PTFE has a very low static friction coefficient.

9.3. Chemical Resistance

9.3.1. Irradiated PTFE is highly resistant to a wide range of acids, including hydrochloric acid, sulfuric acid, and nitric acid.

9.3.2. Irradiated PTFE is highly resistant to a wide range of bases, including sodium hydroxide and potassium hydroxide. This makes it an ideal material for use in applications that involve the handling of basic liquids or gases, such as in the chemical and pharmaceutical industries.

9.4. Water Resistance

9.4.1. Irradiated PTFE is strongly hydrophobic (water shedding). Water cannot readily wet out the surfaces

9.5. Oil Resistance

9.5.1. Irradiated PTFE is oleophobic (oil shedding) and strongly resistant to oils and stains.

9.6. Temperature Resistance

9.6.1. Irradiated PTFE has excellent temperature resistance with chemical inertness and temperature resistance ranging from -200 to 260 °C

9.7. Flexibility

9.7.1. Irradiated PTFE is very flexible and is useful in applications requiring more flexibility than standard PTFE offers.

9.8. Forever Chemicals (initial)

9.8.1. Irradiated PTFE usually contains 100s of ppb of each of the perfluorocarboxylate (PFOA family). The perfluorocarboxylates are randomly formed from chains fractured from the original long PTFE polymer chains with gamma (or e-beam) radiation that react with air instead of crosslinking with other chain fractures.

9.9. Forever Chemicals (over time)

9.9.1. Irradiated PTFE does not further degrade into further forever chemicals such as PFOA or PFOS. Irradiated PTFE does not have the ether bond (C-O-C) that leads to degradation into PFOA related chemicals that can occur in other fluoropolymers (such as fluoroacrylate coatings or PFA polymers). Irradiated PTFE has no natural degradation path into the PFOA family unless it is further irradiated.

9.10. Biocompatibility

9.10.1. Irradiated PTFE is highly biocompatible but it does release a small amount of the PFOA family. Irradiated PTFE's PFOA (and similar) concentration is not normally high enough to require toxicological risk assessment, but PFOA has a measurable presence in biocompatibility extracts from irradiated PTFE containing medical devices.

9.11. Low dielectric constant

9.11.1. Irradiated PTFE has a very low dielectric constant that does not change with temperature or frequency. This property makes irradiated PTFE an excellent insulator for electronic purposes.

9.12. Radiation Resistance

9.12.1. Irradiated PTFE is not suitable for further gamma radiation or e-beam radiation exposure. Additional radiation exposure causes the polymer chains to further break down, significantly changing the properties (and chemical composition) of the material.

9.13. Conclusion - Irradiated PTFE

9.13.1. Irradiated PTFE is useful in applications requiring the performance of PTFE but require additional flexibility than standard PTFE can provide. Irradiated PTFE contains a small amount of all of the length of perfluorocarboxylates (PFOA family), but does not normally further degrade into PFOA (or similar) over time.

10. Expanded Polytetrafluoroethylene (ePTFE)

CAS # - 9002-84-0 (Same as PTFE)

10.1. Summary

10.1.1. ePTFE, or expanded polytetrafluoroethylene, is a woven version of PTFE which is soft, flexible, microporous, air permeable, and fluid impermeable. ePTFE is made from the same polymer as PTFE but expanded to create a porous structure.

10.1.2. Either part of the expansion process creates similar polymer bond fracturing as irradiation or the powder size is reduced by irradiation before expansion - creating a low concentration of perfluorocarboxylates (PFOA family) normally in ePTFE (which is not normally found in unirradiated, and unexpanded PTFE).

10.1.3. Applications for ePTFE are generally applications requiring the passage of air or gas, but the blocking of water or other chemicals. Gore-Tex is a common trade name for ePTFE.

10.2. Low Friction

10.2.1. ePTFE has a very low static friction coefficient.

10.3. Chemical Resistance

10.3.1. ePTFE is highly resistant to a wide range of acids, including hydrochloric acid, sulfuric acid, and nitric acid.

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10.3.2. ePTFE is highly resistant to a wide range of bases, including sodium hydroxide and potassium hydroxide. This makes it an ideal material for use in applications that involve the handling of basic liquids or gases, such as in the chemical and pharmaceutical industries.

10.4. Water Resistance

10.4.1. ePTFE is fluid impermeable while maintaining permeability to gas.

10.5. Oil Resistance

10.5.1. ePTFE is oleophobic (oil shedding) and strongly resistant to oils and stains.

10.6. Temperature Resistance

10.6.1. ePTFE has excellent temperature resistance with chemical inertness and temperature resistance ranging from -200 to 260 °C

10.7. Flexibility

10.7.1. ePTFE is very flexible and is useful in applications requiring more flexibility than standard PTFE offers. However, it does not have the durability of PTFE in abrasive environments.

10.8. Forever Chemicals (initial)

10.8.1. ePTFE usually contains 100s of ppb of each of the perfluorocarboxylate (PFOA family). The perfluorocarboxylates are randomly formed from chains fractured from the original long PTFE polymer chains from either the expanding process or from gamma (or e-beam) radiation used to rubberizes the micropowder feedstock of the ePTFE.

10.9. Forever Chemicals (over time)

10.9.1. ePTFE does not further degrade into further forever chemicals such as PFOA or PFOS. e PTFE does not have the ether bond (C-O-C) that leads to degradation into PFOA related chemicals that can occur in other fluoropolymers (such as fluoroacrylate coatings or PFA polymers). ePTFE has no natural degradation path into the PFOA family unless it is further irradiated.

10.10. Biocompatibility

10.10.1. ePTFE is highly biocompatible but it does release a small amount of the PFOA family. ePTFE's PFOA concentration is not normally high enough to require toxicological risk assessment, but PFOA has a measurable presence in biocompatibility extracts from ePTFE containing medical devices.

10.11. Low dielectric constant

10.11.1. ePTFE has a very low dielectric constant that does not change with temperature or frequency. This property makes ePTFE an excellent insulator for electronic purposes.

10.12. Radiation Resistance

10.12.1. ePTFE is not suitable for gamma radiation or e-beam radiation exposure. Additional radiation exposure causes the polymer chains to further break down, significantly changing the properties (and chemical composition) of the material.

10.13. Conclusion - ePTFE

10.13.1. ePTFE is useful in applications requiring the gas to be permeable with fluid impermeability. ePTFE contains a small amount of all of the length of perfluorocarboxylates (PFOA family), but does not normally further degrade into PFOA (or similar) over time.

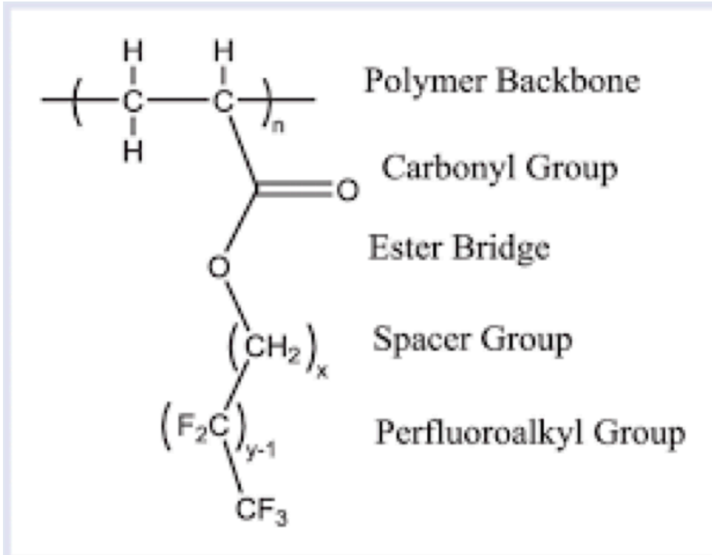
11. Polyfluoroacrylates

CAS # - Multiple (Example - 25087-17-6)

11.1. Summary

11.1.1. Polyfluoroacrylates are a group of polymers primarily formed from an acrylic (non-fluorinated) polymer backbone with side chain fluorotelomers connected by an ester bridge.

11.1.2. Example -

11.1.3. 

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11.1.4. Polyfluoroacrylates are used as coatings, primarily on fabric, to provide water repellency. The ester bridge has a similar weak (low bond dissociation energy) C-O-C bond as polyfluoroxy alkane (PFA) polymer resulting in fracturing of the fluorinated side chain from the main polymer creating moderate concentrations of perfluorocarboxylates (PFOA family).

11.1.5. A common usage of polyfluoroacrylates, outside of outerwear, is on the washing instructions or country of origin fabric tag in most clothing to maintain the quality of the written instructions over time.

11.2. Low Friction

11.2.1. Polyfluoroacrylates have a very low static friction coefficient.

11.3. Chemical Resistance

11.3.1. Polyfluoroacrylates is highly resistant to a wide range of acids, including hydrochloric acid, sulfuric acid, and nitric acid.

11.3.2. Polyfluoroacrylates is highly resistant to a wide range of bases, including sodium hydroxide and potassium hydroxide.

11.4. Water Resistance

11.4.1. Polyfluoroacrylates are hydrophobic and strongly resistant to water.

11.5. Oil Resistance

11.5.1. Polyfluoroacrylates are oleophobic (oil shedding) and strongly resistant to oils and stains.

11.6. Temperature Resistance

11.6.1. Polyfluoroacrylates have excellent temperature resistance with chemical inertness and temperature resistance ranging from -200 to 260 °C

11.7. Flexibility

11.7.1. Polyfluoroacrylates are very flexible and maintain the flexibility of the fabric they are applied to. However, they do not have the durability of PTFE in abrasive environments.

11.8. Forever Chemicals (initial)

11.8.1. Polyfluoroacrylates usually contain up to 1 ppm of each of the perfluorocarboxylate (PFOA family). The perfluorocarboxylates are randomly formed from side chains fracturing during manufacturing and application.

11.9. Forever Chemicals (over time)

11.9.1. Polyfluoroacrylates do further degrade into further forever chemicals such as PFOA or PFOS as more of the side chain fluorochains fracture at the C-O-C bond. The material would also be expected to lose some of its water and oil repellency over time as side chain fluorochains fracture from the acrylic polymer backbone.

11.10. Biocompatibility

11.10.1. Polyfluoroacrylates are reasonably biocompatible but they do release an amount of the PFOA family. Polyfluoroacrylates PFOA concentration will often be high enough to require toxicological risk assessment.

11.10.2. Polyfluoroacrylates, like most acrylics, contain a small amount of acrylic monomer. Most acrylic monomers are known human allergens and need to be evaluated in biocompatibility testing of a polyurethane material.

11.11. Low dielectric constant

11.11.1. Polyfluoroacrylates have a low dielectric constant that does not change with temperature or frequency. This property makes Polyfluoroacrylates excellent insulators for electronic purposes.

11.12. Radiation Resistance

11.12.1. Polyfluoroacrylates are not suitable for gamma radiation or e-beam radiation exposure. Additional radiation exposure causes the polymer chains to further break down, significantly changing the properties (and chemical composition) of the material and accelerating side chain fracturing.

11.13. Conclusion - Polyfluoroacrylates

11.13.1. Polyfluoroacrylates are very useful in applications requiring fluoropolymer performance (water / oil repellency, dielectric constant, or low friction) from a very thin coating (such as fabrics or small electronic components). Polyfluoroacrylates contain an amount of all of the length of perfluorocarboxylates (PFOA family) and do further degrade into PFOA (or similar) over time.

11.13.2. For very harsh environmental conditions, other materials do not have the same level of hydrophobic or oleophobic performance.

12. Fluoroelastomers (FKM)

CAS # - multiple (example - 9011-17-0)

12.1. Summary

12.1.1. A fluoroelastomer is a fluorocarbon-based synthetic rubber. Fluorine Kautschuk Material (FKM) fluoroelastomer all contain fluorovinyldiene monomer as a base material and do not contain the side change ether (C-O-C) fluoro chain of perfluoroelastomers (FFKM).

12.1.2. FKM can have variations in chemical structure. This listing is to include all non-silicone, non-side chain fluoro vinyldiene based fluoro rubbers including phosphorus and nitrogen based fluoroelastomers (PNF).

12.2. Low Friction

12.2.1. FKM has a moderate static friction coefficient making FKM less useful in applications requiring low friction.

12.3. Chemical Resistance

12.3.1. FKM is resistant to a wide range of acids, including hydrochloric acid, sulfuric acid, and nitric acid but not as resistant as FFKM.

12.3.2. FKM is highly resistant to a wide range of bases, including sodium hydroxide and potassium hydroxide. This makes it an ideal material for use in applications that involve the handling of basic liquids or gases, such as in the chemical and pharmaceutical industries.

12.4. Water Resistance

12.4.1. FKM is strongly hydrophobic (water shedding). Water cannot readily wet out the surfaces and FKM maintains its water resistance even under moderate abrasion.

12.5. Oil Resistance

12.5.1. FKM is oleophobic (oil shedding) and strongly resistant to oils and stains.

12.6. Temperature Resistance

12.6.1. FKM has good temperature resistance with chemical inertness and temperature resistance ranging from -26 to 230 °C, but inferior to FFKM.

12.7. Flexibility

12.7.1. FKM is very flexible and very useful in sealing applications requiring flexibility or complete sealing.

12.7.2. FKM is also resistant to explosive decompression.

12.8. Forever Chemicals (initial)

12.8.1. FKM is commonly manufactured with an emulsion process that involves a C6 fluorosulphonate surfactant such as the Capstone family by Chemours. These complex surfactants degrade into 6:2 fluorotelomer sulphonate (6:2 FTS) up to 100 ppm in the FKM, and to small concentrations (<100 ppb) of C4-C7 short chain fluorocarboxylates (PFHpA and smaller).

12.8.2. Technically, these are not currently classified as PBT or vPvB in the EU, but are very similar to substances that meet that classification and would be regulated under the proposed EU PFAS restrictions.

12.8.3. The C6 fluorosurfactants used in FKM manufacturing could likely be phased out, but it would take time and validation.

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12.9. Forever Chemicals (over time)

12.9.1. FKM does not degrade significantly further into forever chemicals. Further amounts of the 6:2 FTS fluorotelomer sulphonate would be expected to further degrade into shorter chain perfluorocarboxylates but that would only change the concentrations of the fluoro salts in the FKM materials.

12.10. Biocompatibility

12.10.1. FKM is reasonably biocompatible but FKM does release an amount of the PFOA family and a reasonable amount of 6:2 FTS. Neither should be high enough to require a toxicological justification.

12.11. Low dielectric constant

12.11.1. FKM has good dielectric and insulating properties, but these properties do vary with temperature.

12.12. Radiation Resistance

12.12.1. FKM is not suitable for gamma radiation or e-beam radiation exposure. Radiation exposure causes the polymer chains to break down, significantly changing the properties (and chemical composition) of the material.

12.13. Conclusion - FKM

12.13.1. FKM is a very important fluororubber for chemical seals and requirements requiring rubber with very high chemical resistance and flexibility.

12.13.2. The standard process for manufacturing FKM commonly involves a C6 surfactant that degrades into 6:2 FTS and short chain perfluorocarboxylates (short chain members of the PFOA family). This surfactant is likely replaceable in the manufacturing process, but will take time. Bisphenol AF (another PFAS) is commonly used as a cross linking agend for FKM. Approved FKM derogations will also require derogations for these chemicals in FKM.

13. Perfluoroelastomers (FFKM)

CAS # - multiple (example - 26425-79-6)

13.1. Summary

13.1.1. Perfluoroelastomeric compounds contain a higher amount of fluorine than FKM fluoroelastomers. FFKM perfluoroelastomers all contain fluorovinyldiene monomer as a base material but, unlikely FKM, do contain a side chain ether (C-O-C) connected to an additional fluorochain. Perfluoroelastomers generally exhibit higher compression set values and are the most expensive of all elastomers.

13.1.2. FFKM can have variations in chemical structure similar to variations in FKM.

13.2. Low Friction

13.2.1. FFKM has a moderate static friction coefficient making FFKM less useful in applications requiring very low friction.

13.3. Chemical Resistance

13.3.1. FFKM is resistant to a wide range of acids, including hydrochloric acid, sulfuric acid, and nitric acid but not as resistant as FFKM.

13.3.2. FFKM is highly resistant to a wide range of bases, including sodium hydroxide and potassium hydroxide. This makes it an ideal material for use in applications that involve the handling of basic liquids or gases, such as in the chemical and pharmaceutical industries.

13.4. Water Resistance

13.4.1. FFKM is strongly hydrophobic (water shedding). Water cannot readily wet out the surfaces and FKM maintains its water resistance even under moderate abrasion.

13.5. Oil Resistance

13.5.1. FFKM is oleophobic (oil shedding) and strongly resistant to oils and stains.

13.6. Temperature Resistance

13.6.1. FFKM has excellent temperature resistance with chemical inertness and temperature resistance ranging from -50 to 330 °C

13.7. Flexibility

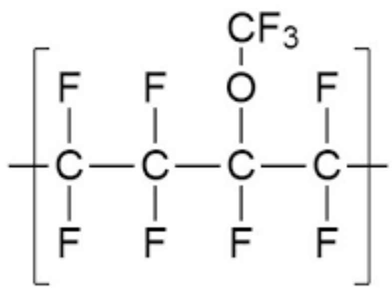
13.7.1. FFKM is very flexible and very useful in sealing applications requiring flexibility or complete sealing.

13.8. Forever Chemicals (initial)

13.8.1. FFKM is commonly manufactured with an emulsion process that involves a C6 fluorosulphonate surfactant such as the Capstone family by Chemours. These complex surfactants degrade into 6:2 fluorotelomer sulphonate (6:2 FTS) up to 100 ppm in the FKM, and to small concentrations (<100 ppb) of C4-C7 short chain fluorocarboxylates (PFHpA and smaller).

13.8.2. The C6 fluorosurfactants used in FKM manufacturing could likely be phased out, but it would take time and validation.

13.8.3. FFKM commonly has a side change fluorochain connected by a C-O-C ether bond. This bond will fracture contributing additional short chain fluorocarboxylates (shorter versions of PFOA family).



Perfluoroelastomer (FFKM)

13.9. Forever Chemicals (over time)

13.9.1. FFKM has C-O-C side chains that will degrade into shorter chain perfluorocarboxylates (shorter version of PFOA family), however these are expected to be very short chain and only contribute marginally to the short chain perfluorocarboxylates present initial from the degradation of the C6 surfactant commonly used in manufacturing of FFKM. Further amounts of the 6:2 FTS fluorotelomer sulphonate would be expected to further degrade into shorter chain perfluorocarboxylates but that would only change the concentrations of the fluoro salts in the FKM materials.

13.10. Biocompatibility

13.10.1. FFKM is reasonably biocompatible but they do release an amount of the PFOA family and a reasonable amount of 6:2 FTS. Neither should be high enough to require a toxicological justification.

13.11. Low dielectric constant

13.11.1. FFKM has good dielectric and insulating properties with little variation over temperature.

13.12. Radiation Resistance

13.12.1. FFKM is not suitable for gamma radiation or e-beam radiation exposure. Radiation exposure causes the polymer chains to break down, significantly changing the properties (and chemical composition) of the material.

13.13. Conclusion - FFKM

13.13.1. FKM is a very important high performance fluororubber for chemical seals and requirements requiring rubber with extreme chemical resistance, temperature resistance, and/or flexibility.

13.13.2. The standard process for manufacturing FFKM commonly involves a C6 surfactant that degrades into 6:2 FTS and short chain perfluorocarboxylates (short chain members of the PFOA family). This surfactant is likely replaceable in the manufacturing process, but will take time. Bisphenol AF (another PFAS) is commonly used as a cross linking agend for FFKM. Approved FFKM derogations will also require derogations for these chemicals in FFKM.

14. Polyvinyldienefluoride (PVDF)

CAS # - 24937-79-9

14.1. Summary

14.1.1. Polyvinylidene fluoride or polyvinylidene difluoride (PVDF) is a highly non-reactive thermoplastic fluoropolymer produced by the polymerization of vinylidene difluoride.

14.1.2. PVDF is commonly used as a specialty plastic for piping, sheet, tubing, and films. PVDF powder is common in outdoor paints. PVDF is also used as the cathode binder in lithium batteries and supercapacitors.

14.1.3. Note - irradiated PVDF is a more flexible version of PVDF caused by gamma or e-beam radiation of a PVDF polymer. Irradiated PVDF does not have a separate listing in this document, but does undergo the same formation of perfluorocarboxylates (PFOA family) as irradiated PTFE.

14.2. Low Friction

14.2.1. PVDF has a low static friction coefficient, but higher than PTFE.

14.3. Chemical Resistance

14.3.1. PVDF is highly resistant to a wide range of acids, including hydrochloric acid, sulfuric acid, and nitric acid.

14.3.2. PVDF is highly resistant to a wide range of bases, including sodium hydroxide and potassium hydroxide. This makes it an ideal material for use in applications that involve the handling of basic liquids or gases, such as in the chemical and pharmaceutical industries.

14.4. Water Resistance

14.4.1. PVDF is strongly hydrophobic (water shedding). Water cannot readily wet out the surfaces

14.5. Oil Resistance

14.5.1. PVDF is oleophobic (oil shedding) and strongly resistant to oils and stains.

14.6. Temperature Resistance

14.6.1. PVDF has decent temperature resistance with chemical inertness and temperature resistance ranging from -20 to 140 °C, but inferior to PTFE or PFA.

14.7. Flexibility

14.7.1. PVDF is only moderately flexible and requires irradiation to be fully flexible.

14.8. Forever Chemicals (initial)

14.8.1. Unirradiated PVDF does not initially contain any PFOA or PFOS family of chemicals. Irradiated PVDF contains similar perfluorocarboxylate (PFOA family) concentrations (100 of ppb of each) as irradiated PTFE.

14.9. Forever Chemicals (over time)

14.9.1. PVDF does not degrade into forever chemicals such as PFOA or PFOS. PVDF does not have the ether bond (C-O-C) that leads to degradation into PFOA related chemicals that can occur in other fluoropolymers (such as fluoroacrylate coatings or PFA polymers).

14.10. Biocompatibility

14.10.1. PVDF is highly biocompatible and does not normally release any substance that would require toxicological evaluation for invasive or implantable medical devices.

14.11. Low dielectric constant

14.11.1. PVDF has a moderate dielectric constant and is not as useful as PTFE for electrical applications requiring insulation.

14.12. Radiation Resistance

14.12.1. PVDF shows good resistance to gamma and e-beam radiation, but less than PEEK.

14.12.2. Irradiated PVDF is PVDF irradiated in a controlled manner to reduce the durometer ('rubberize') of the PVDF polymer. However, irradiation of PVDF also creates small concentrations of the PFOA family of various lengths.

14.13. Conclusion - PVDF

14.13.1. Standard PVDF (unirradiated) is one of the safety polymers available with no forever chemicals and excellent biocompatibility. PVDF has performance characteristics than PTFE and each is often used in applications that are not as suitable for the other fluoropolymer.

15. Nitrile Rubber (NBR)

CAS # - 9003-18-3

15.1. Summary

15.1.1. Nitrile rubber, also known as nitrile butadiene rubber, NBR, Buna-N, and acrylonitrile butadiene rubber, is a synthetic rubber derived from acrylonitrile and butadiene.

15.1.2. Nitrile rubber has many different compositions and is one of the most common gasket and sealing materials.

15.1.3. Nitrile rubber is not a PFAS substance, and is included in this report as a potential substitute.

15.2. Low Friction

15.2.1. Nitrile rubber has a high coefficient of static friction and is not suitable for most applications requiring low friction.

15.3. Chemical Resistance

15.3.1. Nitrile rubber is not resistant to a wide range of acids, including hydrochloric acid, sulfuric acid, acetic acid, and nitric acid.

15.3.2. Nitrile rubber is somewhat resistant to alkaline substances (bases). Nitrile rubber is not suitable for applications requiring strong caustic resistance.

15.4. Water Resistance

15.4.1. Nitrile rubber is strongly resistant to water.

15.5. Oil Resistance

15.5.1. Nitrile rubber is oleophobic (oil shedding) and strongly resistant to oils and stains.

15.6. Temperature Resistance

15.6.1. Nitrile rubber has decent temperature resistance with chemical inertness and temperature resistance ranging from -20 to 120 °C, but inferior to PTFE or PFA.

15.7. Flexibility

15.7.1. Many grades of nitrile rubber have very high flexibility. Nitrile rubber can be manufactured, depending on additives, to a wide range of flexibilities.

15.8. Forever Chemicals (initial)

15.8.1. Nitrile rubber does not contain any PFOA or PFOS family of chemicals.

15.9. Forever Chemicals (over time)

15.9.1. Nitrile rubber does not degrade into forever chemicals such as PFOA or PFOS.

15.10. Biocompatibility

15.10.1. Nitrile rubber can be manufactured in both biocompatible and non-biocompatible forms. There are standard tests for biocompatibility of nitrile rubber.

15.10.2. Nitrile rubber can contain a range of regulated chemicals including orthophthalates (such as DEHP), chlorinated paraffins (such as SCCP), and vulcanizers / allergens (such as ETU). Care has to be taken in choosing nitrile rubber for medical applications.

15.10.3. Some vulcanizers in nitrile rubber degrade in nitrogen environments into nitrosamines, making nitrile rubber a risk material in pharmaceutical manufacturing.

15.11. Low dielectric constant

15.11.1. Nitrile has a high dielectric constant and is not as useful as PTFE for electrical applications requiring insulation.

15.12. Radiation Resistance

15.12.1. Nitrile rubber is not suitable for gamma radiation or e-beam radiation exposure. Radiation exposure causes the polymer chains to break down,

15.13. Conclusion - Nitrile rubber

15.13.1. Nitrile rubber is a common cheap rubber, but does not have the specialized friction, temperature, chemical resistance, or dielectric properties of most fluoropolymers.

15.13.2. Degradation of some of the vulcanizers used in nitrile rubber is also of concern because of its tendency to create nitrosamines.

16. Ethylene propylene diene monomer rubber (EPDM)

CAS # - Multiple (example - 25034-71-3)

16.1. Summary

16.1.1. EPDM is made from ethylene, propylene, and a diene comonomer that is normally crosslinked via sulfur vulcanization

16.1.2. EPDM has many different compositions and is one of the most common rubber materials.

16.1.3. EPDM is not a PFAS substance, and is included in this report as a potential substitute.

16.2. Low Friction

16.2.1. EPDM has a high coefficient of static friction and is not suitable for most applications requiring low friction.

16.3. Chemical Resistance

16.3.1. EPDM is somewhat resistant acids, including hydrochloric acid, sulfuric acid, acetic acid, and nitric acid.

16.3.2. EPDM has good resistance to alkaline substances (bases).

16.4. Water Resistance

16.4.1. EPDM is strongly resistant to water.

16.5. Oil Resistance

16.5.1. EPDM is not resistant to most oils and degrades quickly.

16.6. Temperature Resistance

16.6.1. EPDM has decent temperature resistance with chemical inertness and temperature resistance ranging from -50 to 140 °C, but inferior to PTFE or PFA.

16.7. Flexibility

16.7.1. Many grades of EPDM have very high flexibility. EPDM can be manufactured, depending on additives, to a wide range of flexibilities.

16.8. Forever Chemicals (initial)

16.8.1. EPDM does not contain any PFOA or PFOS family of chemicals.

16.9. Forever Chemicals (over time)

16.9.1. EPDM does not degrade into forever chemicals such as PFOA or PFOS.

16.10. Biocompatibility

16.10.1. EPDM can be manufactured in both biocompatible and non-biocompatible forms. There are standard tests for biocompatibility of nitrile rubber.

16.10.2. EPDM can contain a range of regulated chemicals including vulcanizers / allergens (such as ETU). Care has to be taken in choosing EPDM for medical applications.

16.10.3. Some vulcanizers in EPDM degrade in nitrogen environments into nitrosamines, making nitrile rubber a risk material in pharmaceutical manufacturing.

16.11. Low dielectric constant

16.11.1. EPDM has a moderate dielectric constant and is not as useful as PTFE for electrical applications requiring insulation.

16.12. Radiation Resistance

16.12.1. EDPM has reasonable radiation resistance and is useful in some applications requiring radiation resistance.

16.13. Conclusion - EPDM

16.13.1. EPDM is a common rubber, but does not have all the specialized friction, temperature, or dielectric properties of most fluoropolymers.

16.13.2. Degradation of some of the vulcanizers used in EPDM is also of concern because of its tendency to create nitrosamines.

17. Stainless steel

CAS # - 65997-19-5

17.1. Summary

17.1.1. Stainless steel, also known as inox or corrosion-resistant steel, is an alloy of iron that is resistant to rusting and corrosion. It contains at least 10.5% chromium and usually nickel, and may also contain other elements, such as carbon, to obtain the desired properties.

17.1.2. The alloy's properties, such as luster and resistance to corrosion, are useful in many applications. Stainless steel can be rolled into sheets, plates, bars, wire, and tubing. These can be used in cookware, cutlery, surgical instruments, major appliances, vehicles, construction material in large buildings, industrial equipment (e.g., in paper mills, chemical plants, water treatment), and storage tanks and tankers for chemicals and food products

17.2. Low Friction

17.2.1. Stainless steel has a high coefficient of static friction and is not suitable for most applications requiring low friction.

17.3. Chemical Resistance

17.3.1. Stainless steel is resistant to moderate acids. Some grades are more acid resistance than others, but most grades are not resistant to concentrated acids in particular hydrochloric acid.

17.3.2. Stainless has decent resistance to alkaline substances (bases).

17.4. Water Resistance

17.4.1. Stainless steel is strongly resistant to water.

17.5. Oil Resistance

17.5.1. Stainless steel is strongly resistant to oils.

17.6. Temperature Resistance

17.6.1. Stainless has excellent temperature resistance with chemical inertness and temperature resistance ranging from -200 to 800 °C. No standard polymer has even close to the same temperature resistance.

17.7. Flexibility

17.7.1. Stainless steel has very poor flexibility or compression.

17.8. Forever Chemicals (initial)

17.8.1. Stainless steel has no forever chemicals such as PFOA or PFOS.

17.9. Forever Chemicals (over time)

17.9.1. Stainless does not degrade into forever chemicals such as PFOA or PFOS.

17.10. Biocompatibility

17.10.1. Stainless steel has excellent biocompatibility. However, its cobalt content often requires justification for the EU Medical Device Regulation (EU MDR) and stainless steel's nickel content is an allergen. Neither cobalt or nickel normally extract from stainless steel during testing.

17.11. Low dielectric constant

17.11.1. Stainless steel is conductive and is not useful for electrical applications requiring insulation.

17.12. Radiation Resistance

17.12.1. Stainless steel has excellent radiation resistance and is useful in most applications requiring radiation resistance.

17.13. Conclusion - Stainless Steel

17.13.1. Stainless steel is a safe incompressible material. It is not a suitable substitute for fluoropolymer applications requiring insulation, flexibility, acid resistance, compressibility, or low weight.

18. Fluorosilicone Rubber

CAS # - 63148-56-1

18.1. Summary

18.1.1. Fluorosilicone rubber (also known as fluorinated silicone rubber or FVMQ) is a widely used synthetic elastomer that can be used in a wide range of applications. The mechanical and physical properties of fluorosilicone are very similar to that of silicone rubber, but fluorosilicone rubber offers improved resistance to fuel and mineral oils, while possessing poorer resistance to heated air and gases.

18.1.2. Fluorosilicone can have a varying range of fluorine concentration.

18.2. Low Friction

18.2.1. Fluorosilicone rubber has a moderate coefficient of static friction and is not generally useful in situations requiring very low friction.

18.3. Chemical Resistance

18.3.1. Fluorosilicone rubber is moderately resistant to acids.

18.3.2. Fluorosilicone rubber has only decent resistance to bases and other alkali materials.

18.4. Water Resistance

18.4.1. Fluorosilicone rubber is highly water resistant.

18.5. Oil Resistance

18.5.1. Fluorosilicone rubber has excellent resistance to oils.

18.6. Temperature Resistance

18.6.1. Fluorosilicone rubber has excellent thermal range and can be used continuously up to 300 °C

18.7. Flexibility

18.7.1. Fluorosilicone rubber is very flexible and is suitable for applications requiring significant flexibility.

18.8. Forever Chemicals (initial)

18.8.1. Fluorosilicone rubber commonly has high concentrations of classified D4, D5, and D6 chemicals.

18.8.2. D6 is also scheduled for restriction under the UN Stockholm Convention on Persistent Organic Pollutant, making silicone a poor potential replacement for fluoropolymers.

18.9. Forever Chemicals (over time)

18.9.1. Fluorosilicone rubber does degrade further over time (slowly) in D4, D5, and D6 siloxanes (forever chemicals).

18.10. Biocompatibility

18.10.1. Silicone rubber has reasonable biocompatibility but silicone rubber does generally release substances that require toxicological evaluation for invasive or implantable medical devices. It is common for medical devices using silicone rubber parts to have to conduct toxicological risk assessment of the D6 (and similar siloxanes) that are released from the silicone rubber parts.

18.11. Low dielectric constant

18.11.1. Fluorosilicone rubber has a decently low dielectric constant but not sufficiently low for many electrical insulation applications.

18.12. Radiation Resistance

18.12.1. Fluorosilicone rubber has poor resistance to gamma and e-beam radiation, and degrades into siloxane monomers.

18.13. Conclusion - Fluorosilicone rubber

18.13.1. Fluorosilicone rubber provides performance advances over silicon rubber in some specialized applications in particular applications requiring oil resistance.