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25 March 2024

Project 2: Literary Study on a Polymer

Ultra High Molecular Weight Polyethylene

A Brief Introduction:

Stronger, lighter, and cheaper are recurring themes when searching for a material to use in applications from biomedical to construction. In both of these industries, Ultra High Molecular Weight Polyethylene (UHMWPE) has found its place. Heralded for lubricity, abrasion resistance, impact resistance, and strength-to-weight ratio, UHMWPE has found itself in a vast array of products. These products include, but are not limited to, sails, tents, backpacks, webbing, body armor, armored vehicles, hip and knee replacements, truck lining, textiles, and cutting boards.

UHMWPE in Climbing Equipment

Dyneema is the gold standard in the climbing world for strong and lightweight slings. Dyneema Composite Fabric (also known as Cuben Fiber) is manufactured in combination with polyester to produce a strong fabric that is abrasion, UV, and chemically resistant. HyperLite Mountain Gear reports that, “Dyneema® Composite Fabrics are high-performance, non-woven, rip-stop, composite laminates. “Dyneema® fiber is laid out in opposing grid orientations, sandwiched between thin outer layers of polyester film, and melded together in a high-pressure autoclave. This process results in a highly durable material that is light enough to float on water.”[1] Edelrid, a retail company for climbing products, reports that their 8mm Dyneema sling,

[1] https://www.hyperlitemountaingear.com/pages/dyneema-hyperlite-mountain-gear-technology

weighing in at 19 grams, has a minimum breaking strength (MBS) of 22 Kn![2] To report these numbers, Edelrid has done extensive testing to earn the EN 566 certification, indicating the trusted standard in their product.[3]

Image 1: Dyneema Climbing sling[4]

Image 2: UHMWPE Reinforced helmet[5]

[2] https://edelrid.com/us-en/sport/slings-and-webbings-shop/dyneema-sling-8mm?variant=2700433
[3] https://avs.edelrid.com/images/attribut/EN_566.pdf
[4] https://www.wildcountry.com/en-us/dyneema-sling-10mm-40-ds10_00000

[5] https://tacticalpop-up.com/products/wendy-style-ballistic-high-cut-umhwpe-helmet-anti-bullet-helmet-us-standard-nij-iiia-ballistic-helmet-with-test-report

Image 3: EN 566 Certification details

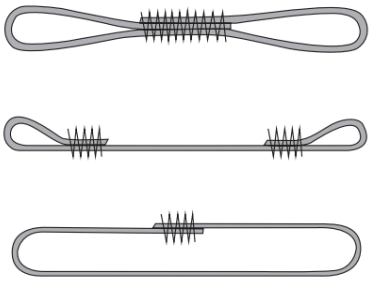
This summary of EN 566 does NOT contain the full details of the standard.
It is a simplified summary to provide an overview of the test methods and safety requirements for the product.
The official version of the standard must be consulted if full information is required. Details of the standard are provided at the end of this summary.

SLING | MOUNTAINEERING EQUIPMENT

EN 566

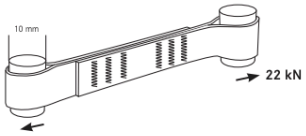
Slings: tape, accessory cord or a piece of rope connected by stitching or some other method. The type and length and not specified.

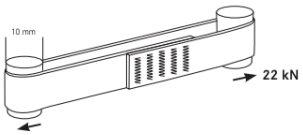
Stitching: where stitching are used for safety and strength purposes (e.g. connections), it should have a contrasting colour or surface texture to the tape.



SAFETY REQUIREMENTS

STATIC STRENGTH TEST





INFORMATION SUPPLIED

The following compulsory information is supplied by the manufacturer on the product:

- Name of manufacturer;
- Breaking strength;
- EN 566;
- Year manufactured;
- CE mark with 4-digit identification number.

For additional information, see either the labelling or the user manual.

Material Structure:

UHMWPE is a linear, synthetic, thermoplastic, meaning it is a synthesized plastic that hardens at low temperatures but becomes moldable above certain temperatures. Ethylene (C2H4) is a gas with molecular weight 28 that forms the polymer polyethylene. The basic chemical formula for polyethylene is (C2H4)n, where n is the degree of polymerization.[6] UHMWPE can consist of up to 200,000 repeat units of polyethylene. The molecular weight of UHMWPE is difficult to measure by traditional means, and thus it is inferred through its intrinsic viscosity to be between 2 and 6 million grams per mole. Its density is approximately 1 gram per cubic centimeter and its unit cell dimensions are a = 0.74 nm, b = 0.493, nm and c = 0.253 nm.[7]

It is often copolymerized with monomers like polypropylene and can consist of up to 50% copolymers and while still being considered UHMWPE under certain industrial standards. The

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6 https://iupac.org/cms/wp-content/uploads/2016/01/Compendium-of-Polymer-Terminology-and-Nomenclature-IUPAC-Recommendations-2008.pdf

7 https://pdf.sciencedirectassets.com/271513/1-s2.0-S0927025619X00142/1-s2.0-S0927025619306597/am.pdf?X-Amz-Security-Token=IQoJb3JpZ2luX2VjEFMaCXVzLWVhc3QtMSJIMEYCIQCUwIzp7kqI6mVPBtd%2B%2F3XvpEH9TFbsrEcBlxIWb87t%2BAIhAPT36CJcfZI7%2BZlmjswnf8ejIrjDAoZ%2FdGAew%2BGtW26yKrMFCGwQBRoMMDU5MDAzNTQ2ODY1IgwpVyk%2BBObki9w%2Fo0oqkAX5aztV6P8jL2YsPB8YwLaI2f00cy23qsBw34Knaco85HDPn5o%2BkI6v6oMDU%2BIE2abRhw1dpUgx5mG29B2Mm7GN76DciPNpLM7w1Fvt8ATx%2Ff07EanHg8JHwqPX8xMq6r2CGSieKEU6LfCj0CQfiKat3ILBF753wTwIICvdFiTCLI7DFAM6tXcsHMuTJ7DKI0i8m1kwVycKQEXk4yfaHuHvSSgXkqC63sN%2FZJ9%2B5Sysw0MtmqG3fhLA%2F0ueYv%2FDS5Zpa%2FgPJ9HDAMsVFmF5UyitJ%2B1SN3hzmWzau7T2Jtl2Csev%2F8WiHbXETU0IB8LaA4FxL5EkyLuPwLei0ovCPYARC8T4zaM9saFO5WsYKeOUAzRvLFRqp2TenIlD2w4pMwwMAixSbA%2Fv9cTUUeZNHd5iwu2WpZofoALfPSn9gXh%2BtngiLgbDgHI8Fkpues%2FcdMk1dohvUJwWNThl1H2q0vp07x%2F47cRVuKA1wkwdcXZuykNLDOyKvvkw4ynDom69GrAclTLr2pdwMxp5AFFuCxDwMVlvjUSOgZVmnLcMKNThNI6ZJDdULF6ysk1T31Pqia81E5afofmIBOVpSMfld4PKoYBqylOlJkYV20B7AdwZi1YGzs5G9AG3G4oK3PcTPiDrlYzF2t1Qw3xRThLcUO%2Fy5KWxN2bEQ1tpaLMkZRrCkAGNOaelhCWC3m4JvCSX2UJorsVMvsaBAH5ysOEOXjEbKgED%2BxVNBC%2BMoR%2BzelZ%2Fc%2FaLkl%2B2Ww%2BmMGMXxSHfR0sw1AV4%2Bn7tWTX1scNJQHGjM%2B3iC7TsfdLg8w9UG%2BssSzSA8kHcRdeO2lPlmLsCanUlq%2BF45n623hOYT3vTHjVFGUqeccNW%2BuJI%2BmCaJPrLZTC8rf6vBjqwAfLqrEv6PJM6uZy0MCMm4mCR32M5gpZlJNxWT0Q3eqTxKY3ooa7udED8SJf82G5%2FkAxhRtytSk7Q40%2BljyYl1jHvGAoj5F2%2B%2FFcO4HRfFDsiPhCO2gWhur8atxkr%2Bp2hg29Kq9GpTAMERnjqKtLZVtIFqIHWqHg9o%2FNU3%2BP64S1Q39TWDuSy7DlVaEx7Sh1%2BceL13M4pMwJi5nXZkhn1%2BY1cjNzGL2nk9mF1syKJ5%2BF6&X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Date=20240324T033940Z&X-Amz-SignedHeaders=host&X-Amz-Expires=300&X-Amz-Credential=ASIAQ3PHCVTY7FJQ4B44%2F20240324%2Fus-east-1%2Fs3%2Faws4_request&X-Amz-Signature=a4f6d711fafd87d96773873ff93c3f720eb5af0b83fa78535fa13f6c16599c56&hash=356ae60b00837f6d3915305b3d337a379ee6601442742ed138ab47183c8318f8&host=68042c943591013ac2b2430a89b270f6af2c76d8dfd086a07176afe7c76c2c61&pii=S0927025619306597&tid=pdf-29495da3-fb7b-467a-80d3-a0e789c69b98&sid=91a0f46a536457402828ff03425784a9afc4gxrqa&type=client

addition of polymers alters the mechanical and physical properties of UHMWPE, however only the monomer ethylene will be considered, as in industries such as the medical field the production of UHMWPE are homopolymers. The configuration of UHMWPE is described as "a two phase composite of crystalline and amorphous phases. The crystalline phase contains chains folded into highly oriented lamellae, with the crystals being orthorhombic in structure. The lamellae are 10-50 nm thick and 10-50 μm long. The lamellae are oriented randomly within the amorphous phase with tie molecules linking individual lamellae to one another."[8] Below are images of UHWMPE under a microscope and its phase diagrams.

Image 4: Light Microscopy of UHMWPE[9]

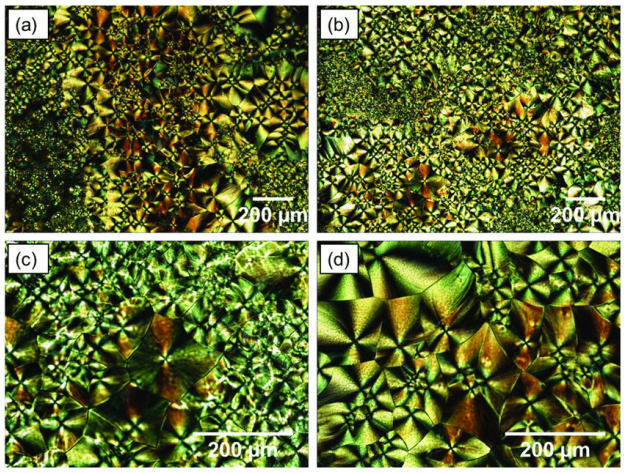
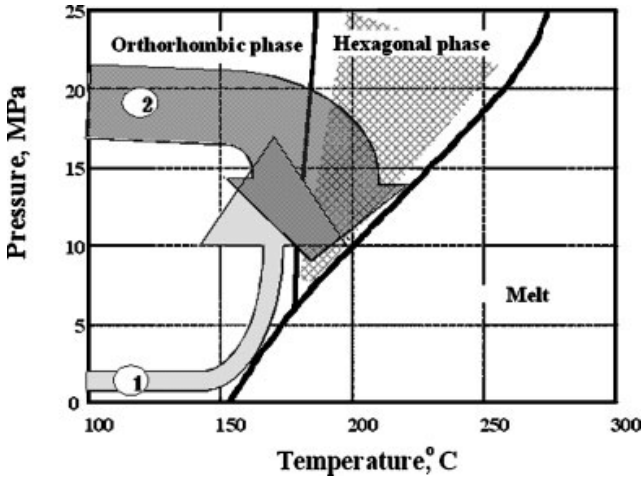


Image 5: Phase Diagram[10]



[8] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3601552/#:~:text=UHMWPE%20is%20a%20linear%20

[9] https://www.researchgate.net/figure/Polarised-light-microscopy-images-of-UHMWPE-Magnification-a-b-4-c-d-10_fig1_336811621

[10] https://www.researchgate.net/figure/Phase-diagram-of-UHMWPE-fibers-relevant-to-the-compaction-processes-as-defined-by_fig4_281583856

Carbon:

electron configuration- 1s2 2s2 2p2

Protons- 6, Neutrons- 6, Electrons- 6 atomic radius- .0914nm

Isotopes: Carbon-13, Carbon-14[11]

Hydrogen:

electron configuration- 1s1

Protons- 1, Neutrons- 1, Electrons- 0 atomic radius- 53pm

Isotopes: Tritium, Deuterium, Protium[12]

Material Properties:

Below are charts of the material properties of UHMWPE. In regard to climbing slings, the tensile strength and specific gravity allow for slings to be lightweight while still incredibly strong. One property to note is the melting temperature, which is relatively low. This is important because under cyclic or continuous friction, such as rubbing against a rope or rock, can lead to the material to melt and ultimately fail.

[11] https://gml.noaa.gov/ccgg/isotopes/chemistry.html

[12] https://byjus.com/chemistry/isotopes-of-hydrogen/#:~:text=What%20are%20the%20Isotopes%20of,tritium%2C%20deuterium%2C%20and%20protium.

Image 6: Material Properties of UHMWPE[13]

Table 1.1
Typical Average Physical Properties of HDPE, UHMWPE

Property	HDPE	UHMWPE
Molecular weight (10^6 g/mole)	0.05–0.25	2–6
Melting temperature (°C)	130–137	125–138
Poisson's ratio	0.40	0.46
Specific gravity	0.952–0.965	0.932–0.945
Tensile modulus of elasticity* (GPa)	0.4–4.0	0.8–1.6
Tensile yield strength* (MPa)	26–33	21–28
Tensile ultimate strength* (MPa)	22–31	39–48
Tensile ultimate elongation* (%)	10–1200	350–525
Impact strength, Izod* (J/m of notch; 3.175 mm thick specimen)	21–214	>1070 (No Break)
Degree of crystallinity (%)	60–80	39–75

*Testing conducted at 23°C.
From Edidin A.A., and S.M. Kurtz. 2000. The influence of mechanical behavior on the wear of four clinically relevant polymeric biomaterials in a hip simulator. *J Arthroplasty* 15:321–331.

[13] https://books.google.com/books?id=bkuFjppEdMcC&printsec=frontcover#v=onepage&q&f=false

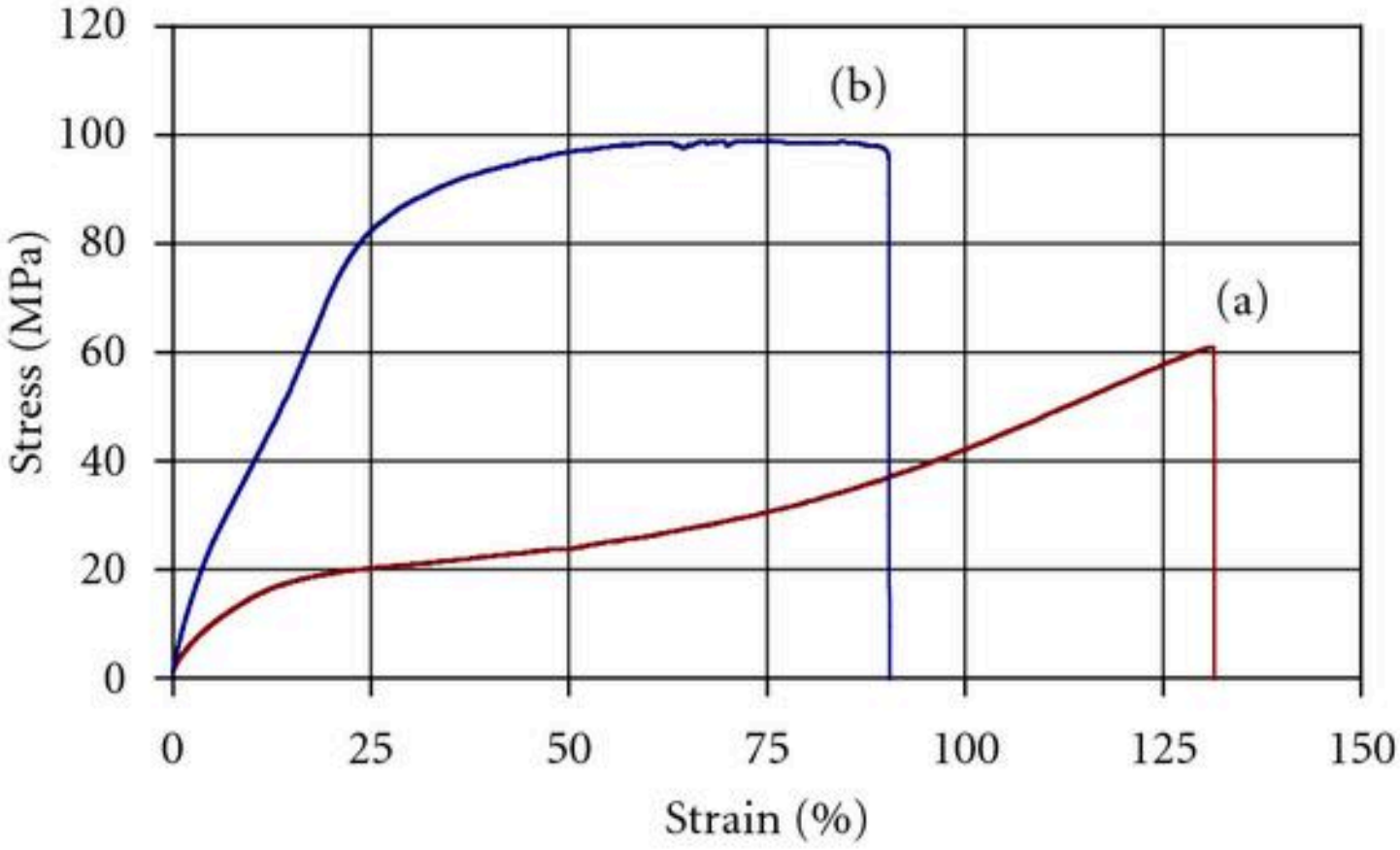
Image 7: Thermal Properties[14]

Material Properties of UHMW Polyethylene - Thermoplastic

Property	Metric	units	English	units
Thermal				
Max Service Temperature	110 - 130	°C	230 -266	°F
Melting Temperature	125 - 138	°C	257 - 280	°F
Insulator or Conductor	Insulator		Insulator	
Specific Heat Capability	1.75e3 - 1.81e3	J/kg °C	0.418 - 0.432	BTU/lb. °F
Thermal Expansion Coefficient	2.34e-4 - 3.6e-4	strain/°C	130 - 200	µstrain/ °F
Eco				
CO2 Footprint	3.16 - 3.49	kg/kg	3.16 - 3.49	lb/lb
Recyclable	Yes		Yes	
Dielectric Manufacturing, Richfield, Wisconsin USA dielectricmfg.com				

[14] https://dielectricmfg.com/resources/knowledge-base/uhmw/

Image 8: Tensile stress-strain curves of (a) Neat UHMWPE (b) UHMWPE-MWCNT[15]



15

https://www.researchgate.net/figure/Tensile-stress-strain-curves-of-a-Neat-UHMWPE-b-UHMWPE-MWCNT_fig1_228484071

Processing and Production

The production of UHMWPE is a process that involves several steps to achieve a material in a usable form. Typically, ethylene must first be synthesized and then polymerized in polyethylene. Special processes are then used to achieve long chains of polyethylene that form UHMWPE. After its initial synthesis, UHMWPE is extruded or injected to form a desired shape, such as sheets, tubes, and rods. The first step would be the synthesis of ethylene, which, according to the University of South Carolina, "The conventional method of producing ethylene is steam cracking of etha

ne in a chemical plant by using extreme temperatures and pressures. This requires a large energy input and releases substantial amounts of carbon dioxide, a greenhouse gas."[16] The next step is to polymerize the ethylene gas in a process known as Ziegler-Natta polymerisation. "In Ziegler-Natta polymerisation, monomers are treated with a catalyst, such as a mixture of titanium chloride (or related compounds, like oxovanadium chloride) with triethylaluminum (or trimethylaluminum). Other components are often added, such as magnesium chloride, to modify the catalyst and improve performance."[17] Finally, the polyethylene is molded into its desired shapes by melting for ram extrusion, injection molding, and compression molding. "In [ram extrusion], the molten UHMWPE is forced through a die using a ram or piston. Ram extrusion allows for the production of continuous profiles, such as rods, tubes, and sheets, with precise

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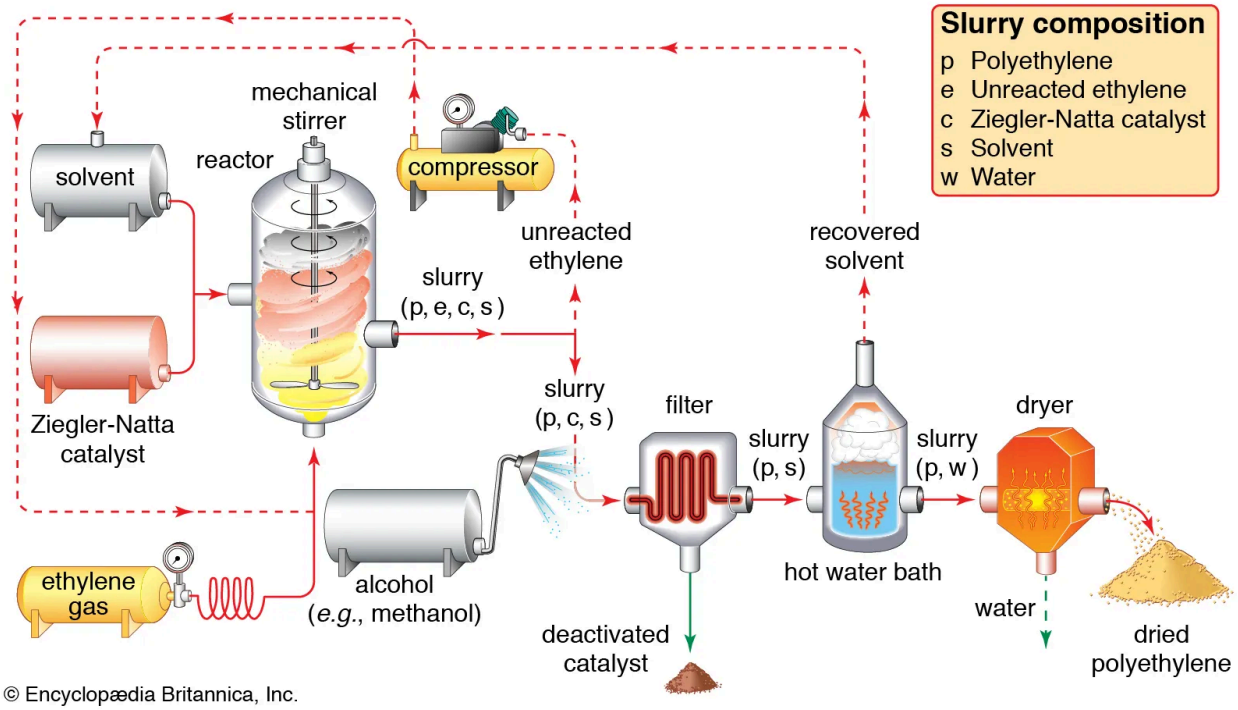
16 https://sc.edu/study/colleges_schools/engineering_and_computing/news_events/news/2021/producing_ethylene_environmentally_safe_process.php#:~:text=The%20conventional%20method%20of%20producing,carbon%20dioxide%2C%20a%20greenhouse%20gas.

17 https://chem.libretexts.org/Bookshelves/General_Chemistry/Book%3A_Structure_and_Reactivity_in_Organic_Biological_and_Inorganic_Chemistry_(Schaller)/IV%3A__Reactivity_in_Organic_Biological_and_Inorganic_Chemistry_2/06%3A_Electrophilic_Addition_to_Alkenes/6.13%3A_Ziegler-Natta_Polymerization#:~:text=In%20Ziegler%2DNatta%20polymerisation%2C%20monomers,the%20catalyst%20and%20improve%20performance.

dimensions and excellent surface finish. Compression molding is another commonly used technique for UHMWPE. In this process, the molten UHMWPE is placed into a mold cavity, and pressure is applied to shape it into the desired form. Compression molding is suitable for producing intricate parts and components with varying thicknesses. [injection molding], the molten UHMWPE is injected into a mold cavity under high pressure. It allows for the production of complex shapes, intricate details, and large quantities of UHMWPE parts with excellent dimensional accuracy."[18]

Image 9: Ziegler-Natta Polymerization[19]



18 https://www.parsethylene-kish.com/separsekish/default.aspx?page=Document&app=Documents&docId=13200&docParId=13166#:~:text=UHMWPE%20is%20typically%20produced%20through,with%20an%20ultrahigh%20molecular%20weight.

19 https://www.britannica.com/science/Ziegler-Natta-catalyst

Image 10: UHMWPE Production process[20]

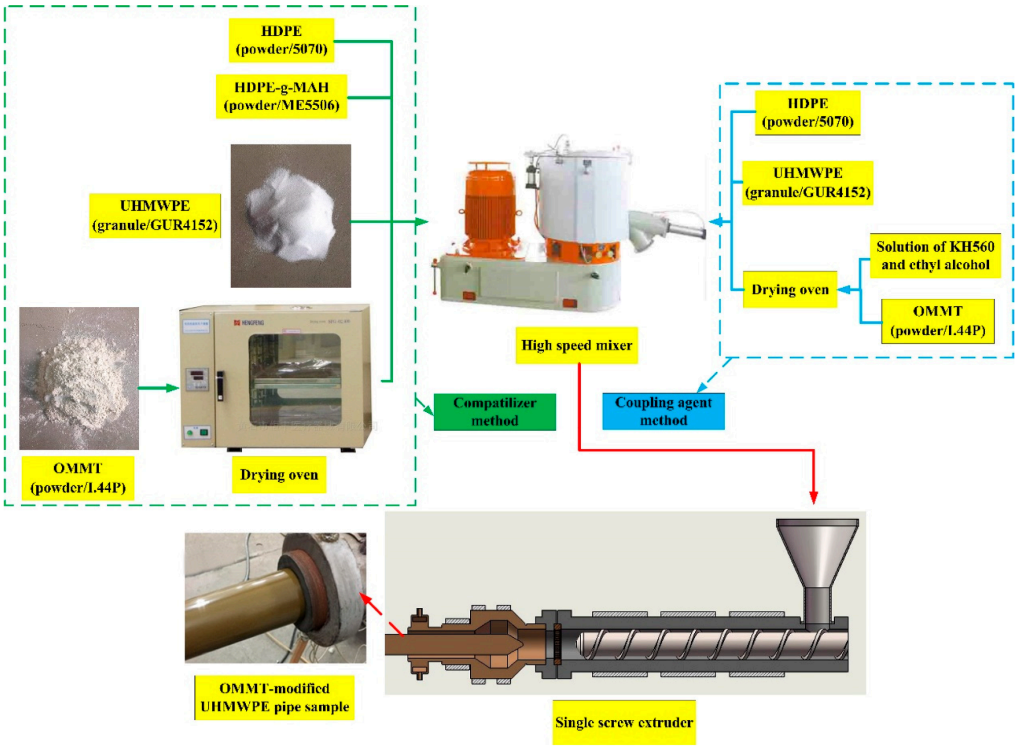
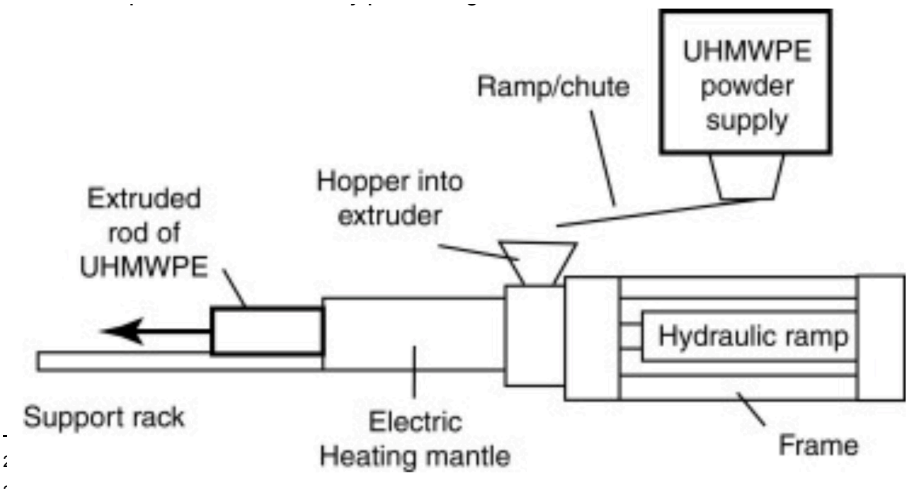


Image 11: Extrusion process[21]



https://www.parsethylene-kish.com/separsekish/default.aspx?page=Document&app=Documents&docId=13200&docParId=13166#:~:text=UHMWPE%20is%20typically%20produced%20through,with%20an%20ultrahigh%20molecular%20weight.

Defects and Durability:

Possible defects in UHMWPE include void formation, creep, inclusions, and chain entanglement. Voids can form from air accumulation within the material during improper manufacturing processes, which reduces density and strength. Creep deformation can occur when the continuous load is applied to UHMWPE, especially when the material is at an elevated temperature. Inclusions in the material structure during production lead to a non-homogenous structure that creates a point of concentration for loads. Inclusions can reduce the strength of the material and lead to failure at lower values than expected. Sufficient entanglement must also be achieved in the polymer structure to maintain its mechanical properties. ScienceDirect says, "The degree of entanglement of the UHMWPE resins and products significantly affects the wear resistance and solubility of the products during processing. The less entangled the resin product, the more likely it is to dissolve evenly during production, resulting in fewer defects and better mechanical properties."[22]

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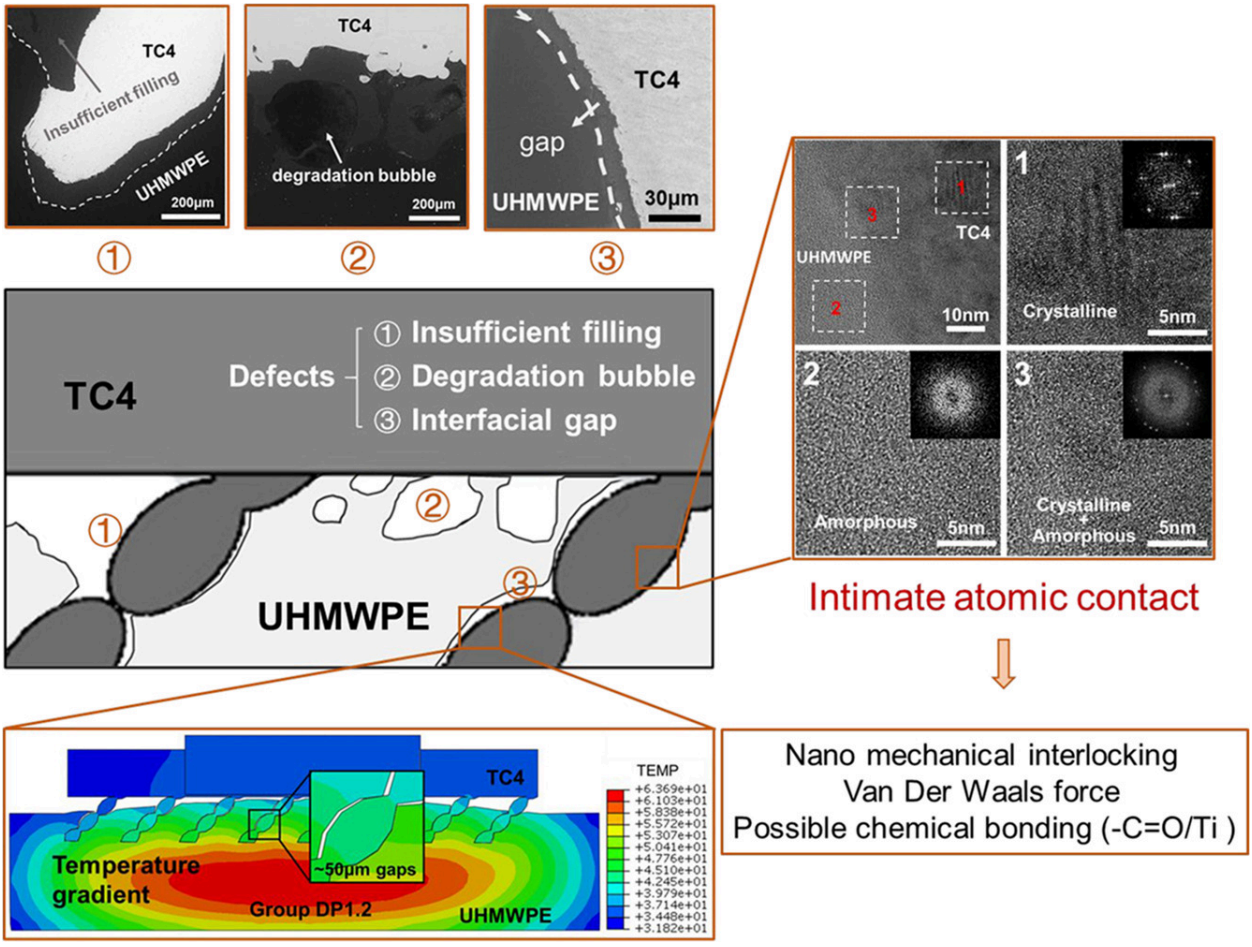
22 https://www.sciencedirect.com/science/article/abs/pii/S0167577X23009680#:~:text=The%20degree%20of%20entanglement%20of%20the%20UHMWPE%20resins%20and%20products,better%20mechanical%20properties%20%5B3%5D.

Image 12: Defects in UHMWPE[23]

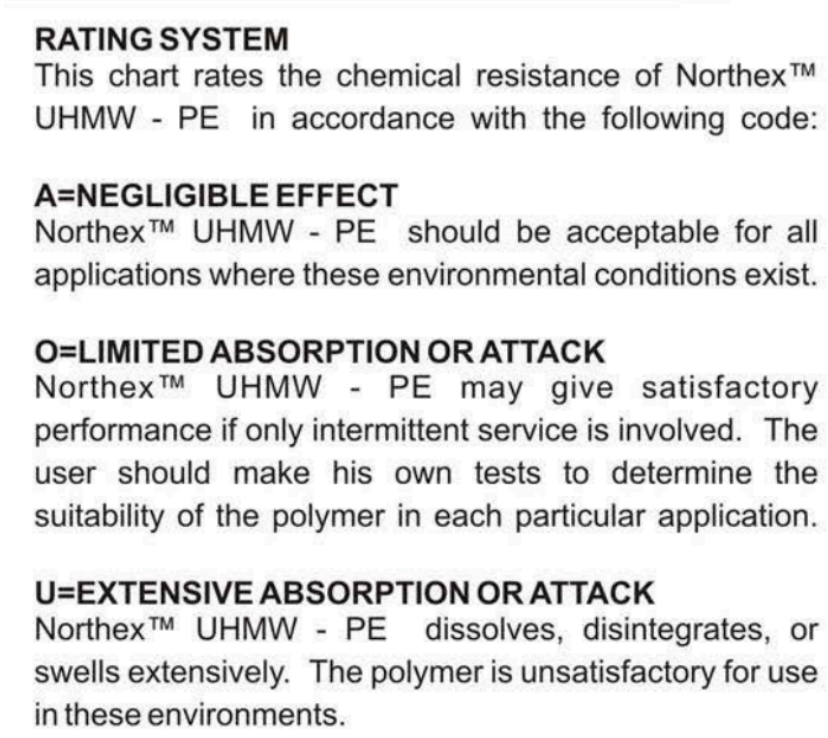


[23] https://www.sciencedirect.com/science/article/pii/S0264127520305232

Measurements and Analysis:

UHMWPE undergoes several extensive testing procedures to validate the physical properties of the material. The National Center for Biotechnology Information provides detailed information on some of the processes and properties that are used and measured.[24] Some key tests that are performed are tensile, hardness, impact, chemical resistance, UV resistance, and creep testing. Universal testing machines are used to test for several load-related properties, while a Charpy impact test is used to test hardness. Chemical resistance is tested with a large selection of chemical substances from acetaldehyde to zinc sulfate, and the effects and deformations are measured to determine acceptability ratings under each chemical.

Image 13: Northern Plastic rating system[25]



RATING SYSTEM
This chart rates the chemical resistance of Northex™ UHMW - PE in accordance with the following code:

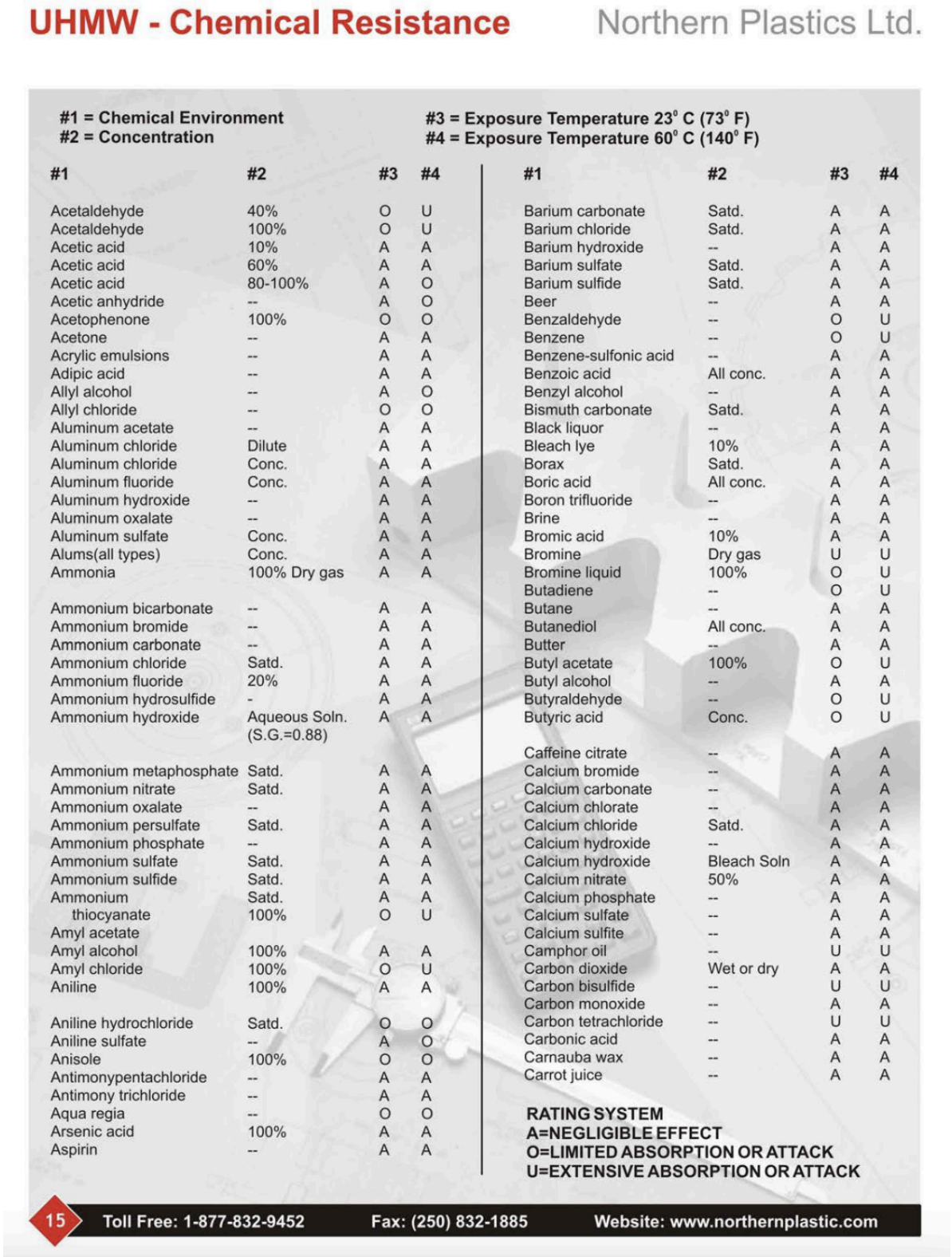
A=NEGLIGIBLE EFFECT
Northex™ UHMW - PE should be acceptable for all applications where these environmental conditions exist.

O=LIMITED ABSORPTION OR ATTACK
Northex™ UHMW - PE may give satisfactory performance if only intermittent service is involved. The user should make his own tests to determine the suitability of the polymer in each particular application.

U=EXTENSIVE ABSORPTION OR ATTACK
Northex™ UHMW - PE dissolves, disintegrates, or swells extensively. The polymer is unsatisfactory for use in these environments.

[24] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7077409/
[25] https://www.northernplastic.com/wp-content/uploads/2020/03/NPL_Pg_014-018.pdf

Image 14: Partial List of Substances Tested by Northern Plastic



UHMW - Chemical Resistance

Northern Plastics Ltd.

#1 = Chemical Environment
#2 = Concentration
#3 = Exposure Temperature 23° C (73° F)
#4 = Exposure Temperature 60° C (140° F)

#1	#2	#3	#4
Acetaldehyde	40%	O	U
Acetaldehyde	100%	O	U
Acetic acid	10%	A	A
Acetic acid	60%	A	A
Acetic acid	80-100%	A	O
Acetic anhydride	--	A	O
Acetophenone	100%	O	O
Acetone	--	A	A
Acrylic emulsions	--	A	A
Adipic acid	--	A	A
Allyl alcohol	--	A	O
Allyl chloride	--	O	O
Aluminum acetate	--	A	A
Aluminum chloride	Dilute	A	A
Aluminum chloride	Conc.	A	A
Aluminum fluoride	Conc.	A	A
Aluminum hydroxide	--	A	A
Aluminum oxalate	--	A	A
Aluminum sulfate	Conc.	A	A
Alums(all types)	Conc.	A	A
Ammonia	100% Dry gas	A	A
Ammonium bicarbonate	--	A	A
Ammonium bromide	--	A	A
Ammonium carbonate	--	A	A
Ammonium chloride	Satd.	A	A
Ammonium fluoride	20%	A	A
Ammonium hydrosulfide	-	A	A
Ammonium hydroxide	Aqueous Soln. (S.G.=0.88)	A	A
Ammonium metaphosphate	Satd.	A	A
Ammonium nitrate	Satd.	A	A
Ammonium oxalate	--	A	A
Ammonium persulfate	Satd.	A	A
Ammonium phosphate	--	A	A
Ammonium sulfate	Satd.	A	A
Ammonium sulfide	Satd.	A	A
Ammonium thiocyanate	Satd. 100%	A O	A U
Amyl acetate			
Amyl alcohol	100%	A	A
Amyl chloride	100%	O	U
Aniline	100%	A	A
Aniline hydrochloride	Satd.	O	O
Aniline sulfate	--	A	O
Anisole	100%	O	O
Antimonypentachloride	--	A	A
Antimony trichloride	--	A	A
Aqua regia	--	O	O
Arsenic acid	100%	A	A
Aspirin	--	A	A

#1	#2	#3	#4
Barium carbonate	Satd.	A	A
Barium chloride	Satd.	A	A
Barium hydroxide	--	A	A
Barium sulfate	Satd.	A	A
Barium sulfide	Satd.	A	A
Beer	--	A	A
Benzaldehyde	--	O	U
Benzene	--	O	U
Benzene-sulfonic acid	--	A	A
Benzoic acid	All conc.	A	A
Benzyl alcohol	--	A	A
Bismuth carbonate	Satd.	A	A
Black liquor	--	A	A
Bleach lye	10%	A	A
Borax	Satd.	A	A
Boric acid	All conc.	A	A
Boron trifluoride	--	A	A
Brine	--	A	A
Bromic acid	10%	A	A
Bromine	Dry gas	U	U
Bromine liquid	100%	O	U
Butadiene	--	O	U
Butane	--	A	A
Butanediol	All conc.	A	A
Butter	--	A	A
Butyl acetate	100%	O	U
Butyl alcohol	--	A	A
Butyraldehyde	--	O	U
Butyric acid	Conc.	O	U
Caffeine citrate	--	A	A
Calcium bromide	--	A	A
Calcium carbonate	--	A	A
Calcium chlorate	--	A	A
Calcium chloride	Satd.	A	A
Calcium hydroxide	--	A	A
Calcium hydroxide	Bleach Soln	A	A
Calcium nitrate	50%	A	A
Calcium phosphate	--	A	A
Calcium sulfate	--	A	A
Calcium sulfite	--	A	A
Camphor oil	--	U	U
Carbon dioxide	Wet or dry	A	A
Carbon bisulfide	--	U	U
Carbon monoxide	--	A	A
Carbon tetrachloride	--	U	U
Carbonic acid	--	A	A
Carnauba wax	--	A	A
Carrot juice	--	A	A

RATING SYSTEM
A=NEGLIGIBLE EFFECT
O=LIMITED ABSORPTION OR ATTACK
U=EXTENSIVE ABSORPTION OR ATTACK

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Health and Safety:

UHMWPE is colorless, odorless, and non-toxic andis regarded as safe for use in most applications. It is non-carcinogenic and there are no known symptoms to exposure. A&C Plastics Inc. recommends that you seek medical attention if exposed and prolonged irritation occurs and "if thermal decomposition occurs, upper respiratory, eye, nose, and throat irritation may result."[26] When working with UHMWPE, personal protective equipment is highly recommended, which includes eye protection, gloves when working with heated material, and adequate ventilation; respiratory protection is not normally required. Overall, UHMWPE is relatively safe to humans and poses little risk to health and safety.

Environmental Sustainability

The environmental sustainability of UHMWPE is a complex issue that is difficult to measure and does not have a clear cut answer. Plastics justifiably face scrutiny over their environmental safety factors, however the use of UHMWPE in place of shorter-lasting plastics can be seen as a net improvement on the environment. UHMWPE is non-biodegradable, and thus single and short-term use products containing the material can be harmful to the environment. Fortunately, UHMWPE is reported to be unlikely to accumulate in biological organisms and is recyclable. Polimaxx says of the disposal methods, "This material may be recycled if unused, or if it has not been contaminated so as to make it unsuitable for its intended use. Shelf life considerations should also be applied in making decisions of this type. Note that properties of a material may change in use, and recycling or reuse may not always be appropriate. Dispose of by: burial in a land-fill specifically licenced to accept chemical and / or pharmaceutical wastes or Incineration in a licenced apparatus (after admixture with suitable combustible material)

[26] https://www.acplasticsinc.com/media/documents/MSDS_UHMW.pdf

Decontaminate empty containers. Observe all label safeguards until containers are cleaned and destroyed."[27] Additionally, the production of UHMWPE is an energy intensive process, specifically polymerization and shaping. The processes release greenhouse gasses to the atmosphere, which pose a serious risk to the environment and climate. However, the durability of UHMWPE can reduce the use of similarly harmful materials and, when used responsibly, produce a net positive on the environment. As with most materials, it is important for companies to make educated and responsible decisions when deciding to use UHMWPE, as well as for consumers to be aware of the possible harm these products may cause.

[27] http://www.irpcmarket.com/upload/document/msds-1527497934.pdf

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