lyondellbasell
Advancing Possible

Advancing Geomembranes with APS *Catalloy* and Masterbatches

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With the support of
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28th April 2020

Agenda

- LyondellBasell at a glance
- Introduction to *Catalloy* technology
- *Hifax* CA10A as modifier for HDPE and MDPE based geomembranes and foils
- *Hifax* CA10A for geomembranes
- Chemical resistance of *Hifax* CA10A
- Masterbatches for geomembranes
- Conclusions

LyondellBasell is a strong, global company delivering outstanding performance

LEADING[1]

#1

- Producer of **polyethylene** in Europe
- Producer of **polypropylene** in North America and Europe
- Producer of **oxyfuels** in North America and Europe
- Producer of **polypropylene compounds** globally
- Licensor of **polyolefin technologies** globally

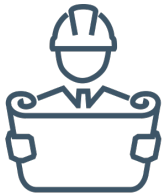
DIVERSE

Many of our **materials** go into products that people use every day, such as food packaging, electronics, children's toys and fuels.

GLOBAL

Every day, our **employees** work around the clock to safely **advance solutions** to our world's biggest challenges.

GROWING



- Increased U.S. ethylene capacity by **23%** since 2012
- Building the first world-scale ***Hyperzone*** **HDPE plant** and world's largest **PO/TBA plant**
- Acquired A. Schulman, expanding our position in the **advanced polymers markets**

One of the world's largest plastics, chemical and refining companies producing products and materials key to advancing solutions to modern challenges

[1] 2018 data as of December 31, 2018

Our products are advancing a range of solutions in nearly every geography and sector of the economy

Cleaner air & fuel efficiency

Stronger, lighter plastics support increased fuel efficiency

Food safety & access

Food packaging and films that improve freshness, portability and extend shelf-life

Clean water

Stronger, longer-lasting pipes used in municipal water systems and key elements used in water filtration systems

CHEMICALS

POLYMERS

ADVANCED POLYMERS

FUELS

TECHNOLOGIES

Sustainable & modern living

Materials that form components used in solar panels, wind turbines, children's toys, cosmetics, leak- and shatter-proof containers

Quality healthcare

Improved medical supplies such as synthetic latex gloves, hand sanitizers, biohazard bags and pill coatings

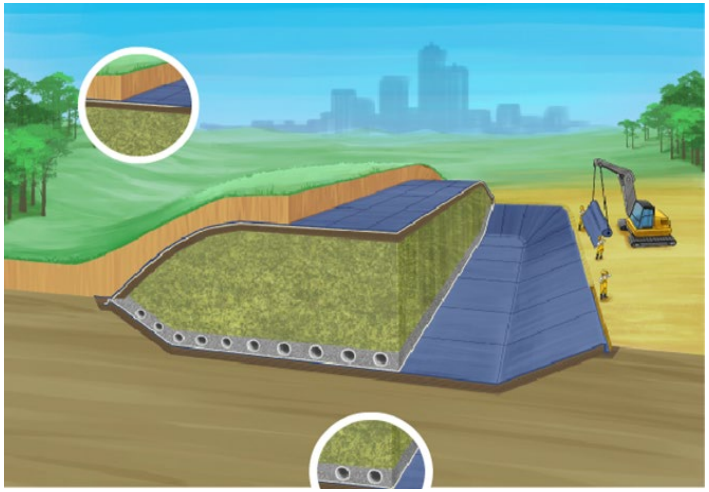
Agricultural efficiency

Lighter machinery, crop protection and soil conditioning used to be more efficient in agroprocessing

Geomembranes

- Geomembranes are impermeable synthetic membrane liners or barriers having one or more primary functions:
  - Separation
  - Reinforcement
  - Filtration
  - Drainage
  - Containment

- Typical applications for Geomembranes are:
  - Construction and Transportation infrastructure
    - Roads, airfields, railroads
    - Tunneling
    - Building foundation (construction)
  - Environmental
    - Reservoirs, canals, dams, embankments
    - Erosion control
    - Landfill liners & landfill covers
    - Mining
    - Aquaculture & agriculture



Geomembranes

ISSUES

- HDPE and MDPE are commonly used polymers to produce geomembranes, however, these materials may lead to issues related to membrane handling, installation, and durability due to one or more of the following material properties:

- **Stiffness**
- **Lack of flexibility**
- **Low impact resistance**[1]
- **Inferior Environmental Stress Cracking Resistance (ESCR)**[2]

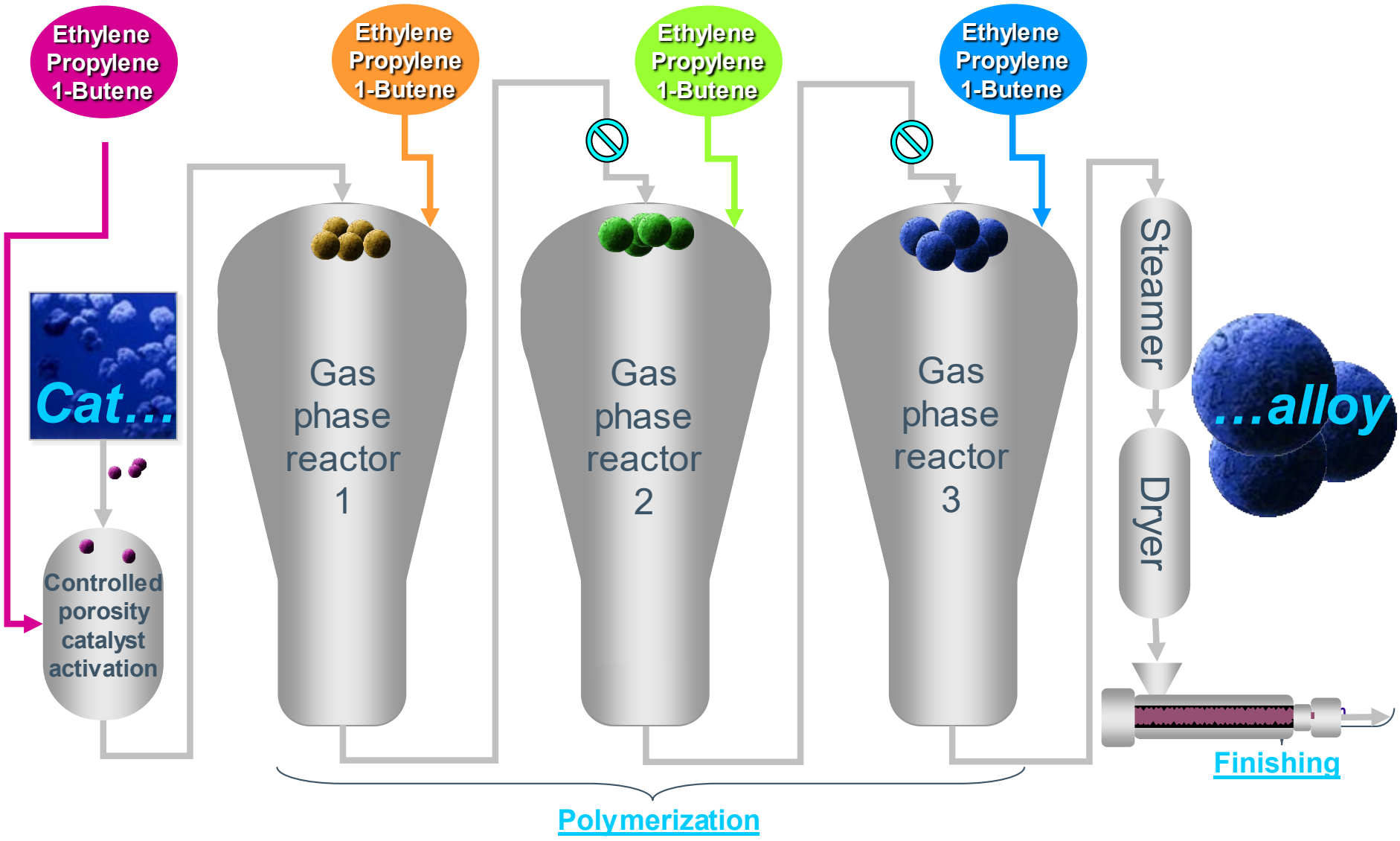
SOLUTION

- ***Catalloy* produced grades, like *Hifax* CA10A,** are used in various waterproof membrane applications and can also be used as a HDPE/MDPE modifier owing to the following key properties:

✓**High flexibility**
✓**Good puncture resistance**
✓**Excellent tear and impact resistance**
✓**Very good dimensional stability**
✓**Good Environmental Stress Cracking Resistance (ESCR)**
✓**Durability**

[1] especially in cold environments
[2] key property for some membrane applications

Catalloy Polymerization Technology



Benefits of the *Catalloy* technology

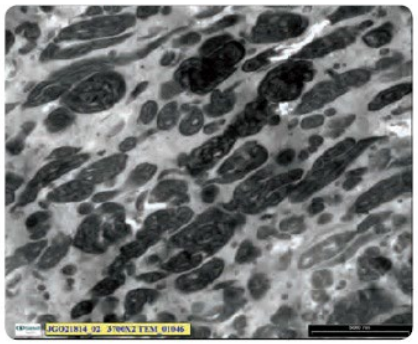
Physical Property Performance

- *Catalloy* technology creates a PP/EPR (Ethylene Propylene Rubber) alloy directly in the polymerization reactors

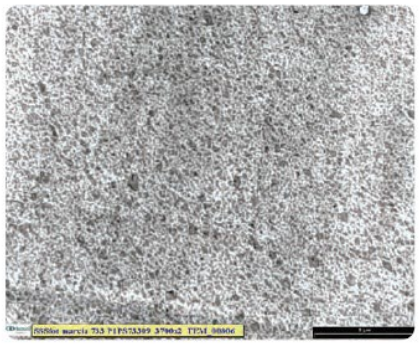
- This results in a very fine and uniform rubber dispersion that allows for optimum:
  - Impact/Stiffness Balance
  - Thermal Resistance
  - Cold Temperature Impact
  - Creep Resistance
  - Softness
  - Toughness
  - Tear Resistance
  - Puncture Resistance
  - Controlled Shrinkage
  - Good Dimensional Stability

Comparative structure
EPR physical blend vs *Hifax* CA10A

Ethylene Propylene Rubber Blend



Hifax CA10A



TEM (transmission electron microscopy) – 3700X

Catalloy Production Assets

- Europe
  - Italy – Ferrara (1990)
  - Netherlands – Moerdijk (1997)
  - Italy – Ferrara (Pilot plant)
- North America
  - USA – Bayport (1991)
  - USA – Lake Charles (2005)

Catalloy produced *Hifax* CA10A as modifier for PE based membranes

Hifax CA10A as modifier for HDPE and MDPE based membranes

This study investigates the properties of PE / *Hifax* CA10A blends in order to understand if it can improve the properties of HDPE or MDPE in membrane or foil applications.

Agenda for *Catalloy* produced *Hifax* CA10A as modifier for PE based membranes

- Testing
- Sheet characterization
- Plaque characterization
- ESCR and Weldability
- Summary

Hifax CA10A for flexible sheet (barefoot additives package)

Hifax CA 10 A is a reactor TPO (thermoplastic polyolefin) manufactured using the LyondellBasell proprietary *Catalloy* process technology. It is suitable for industrial applications where a combination of good processability and excellent softness is required. It is widely used as building block resin for flexible water-proofing membranes.

Hifax CA 10 A exhibits low stiffness, low hardness and good impact resistance. The grade is available in natural pellet form.

Typical Properties	Nominal Value	Units	Test Method
Physical			
Melt Flow Rate, (230 °C/2.16 kg)	0.6	g/10 min	ISO 1133-1
Density, (23 °C, Method A)	0.88	g/cm³	ISO 1183-1
Mechanical			
Flexural Modulus	90	MPa	ISO 178
Tensile Stress at Break	11	MPa	ISO 527-1, -2
Tensile Stress at Yield	No Yield Pt	MPa	ISO 527-1, -2
Tensile Strain at Break	500	%	ISO 527-1, -2
Tensile Strain at Yield	No Yield Pt	%	ISO 527-1, -2
Impact			
Charpy Impact Strength - Notched			
(23 °C)	No Break		ISO 179
(-20 °C)	110	kJ/m²	ISO 179
Note: Failure Mode - Partial Break			
(-40 °C)	5	kJ/m²	ISO 179
Note: Failure Mode - Complete Break			
Hardness			
Shore Hardness, (Shore D, 15 sec)	30		ISO 868
Thermal			
Vicat Softening Temperature, (A50)	60	°C	ISO 306
Heat Deflection Temperature B, (0.45 MPa, Unannealed)	40	°C	ISO 75B-1, -2
DSC Melting Point	142	°C	ISO 11357-3
Optical			
Gloss, (60°, 45 mil)	85		ASTM D2457

Intermaterial characteristics: PE vs *Hifax* CA10A

■ **HDPE**	Very low flexibility (900-950 Mpa)	Very low Impact resistance	Very good chemical resistance	Low resistance at high temperature . Limited in service temperature	Very low dimentional stability	High puncture resistance	Good hot w edge w elding	Good durability
■ **MDPE**	Low flexibility (600-650 MPa)	Low impact resistance	Good chemical resistance	Low er resistance at high temperature . Limited in service temperature	Low dimensional stability	High puncture resistance	Good hot w edge w elding	Good durability
■ **LLDPE - VLDPE**	Flexible	Low impact resistance	Good chemical resistance	Low thermal resistance	Medium dimensional stability	High puncture resistance	Good hot w edge w elding	Good durability
■ ***Hifax* CA10A**	Flexible	Excellent impact resistance	Good chemical resistance	Good high and low thermal resistance	Good dimensional stability	Good puncture resistance	Very good hot w edge and air w elding (details)	Good durability

Testing

- Typical properties that are meaningful in geomembrane applications are examined for HDPE / *Hifax* CA10A blends and compared to the properties of a 100% HDPE control, as well as to those of HDPE / LLDPE blends.

- In particular, test results are presented for physical properties, ESCR, weldability window, and UV weathering performances of HDPE and MDPE blended with the following two materials, at both 20 wt% and 40 wt % incorporation rates:
  - commercial *Catalloy* produced *Hifax* CA10A by LyondellBasell, referred here as flexible polypropylene (fPP)
  - commercial LLDPE produced by Polimeri Europa.

- Base HDPE and MDPE Materials:
  - HDPE : *Lupolen* 5021DX (density = 0.950 g/cc)
  - MDPE : *Lupolen* 3721C (density = 0.937 g/cc)

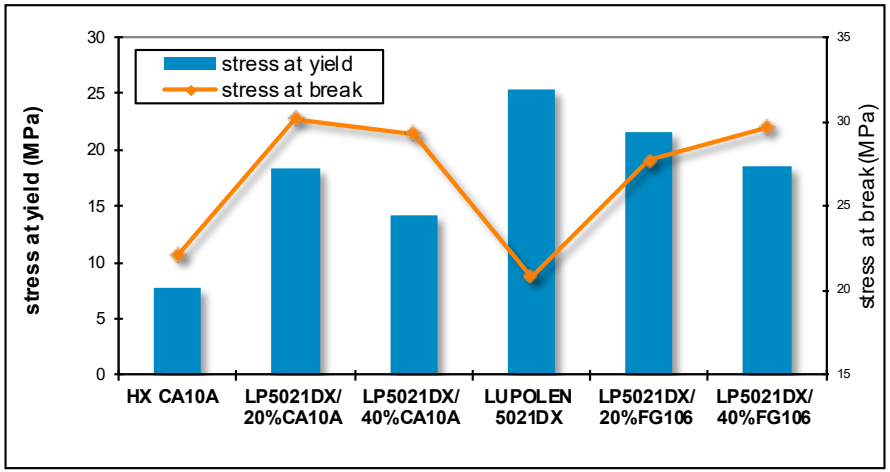
- Modifiers:
  - fPP: *Hifax* CA10A (high EPR level; density = 0.89 g/cc)
  - LLDPE: *Clearflex* FG106 (ethylene-hexene copolymer; density = 0.918 g/cc)

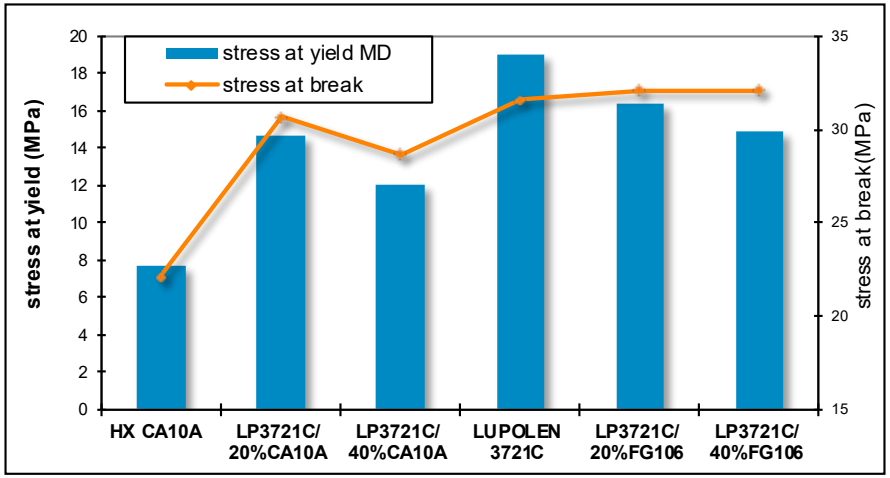
Sheet characterization: Tensile properties

- For “tensile strength at break” there seem to be a synergistic effect between LP5021DX and *Hifax* CA10A **[blends have higher strength than both materials – strain hardening effect]**

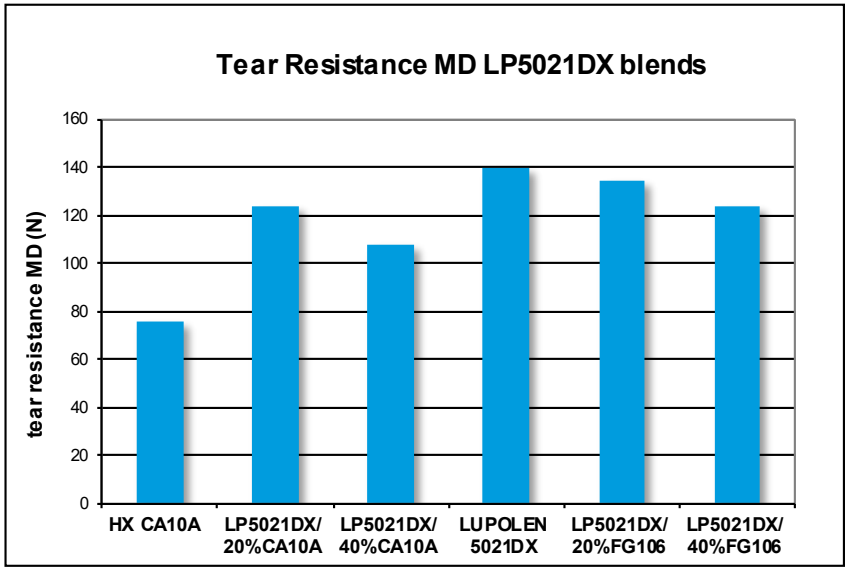
- “Tensile stress at yield / stress at break balance” of the blends with *Hifax* CA10A is very good if compared with blends with LLDPE (FG106) **[similar stress at break but lower stress at yield, the material is softer]**

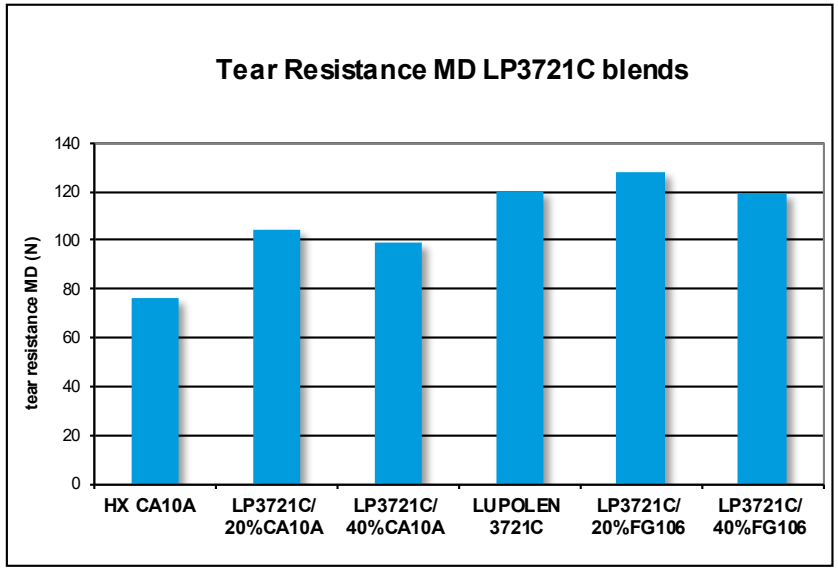
- With MDPE LP3721C “Tensile stress at yield / stress at break balance” of the blends with *Hifax* CA10A is very good if compared with blends with LLDPE (FG106) **[similar stress at break but lower stress at yield, the material is softer]**





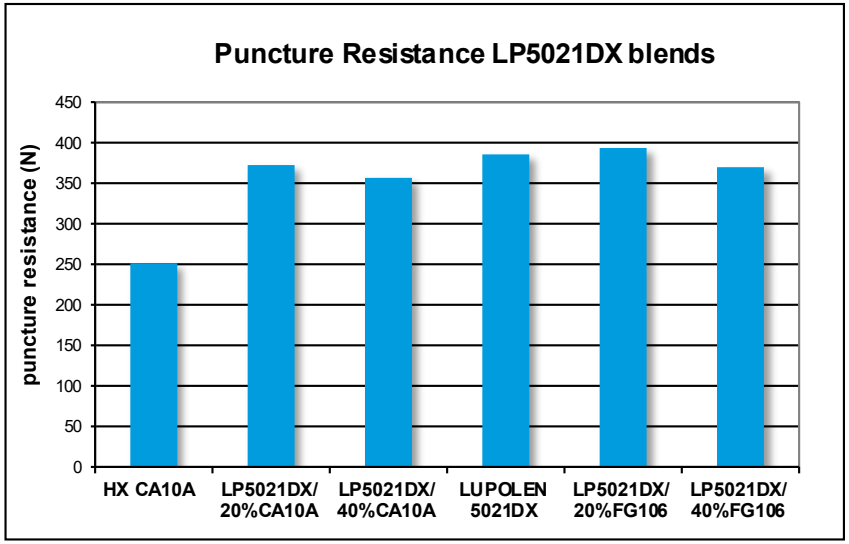
Sheet characterization: Tear resistance

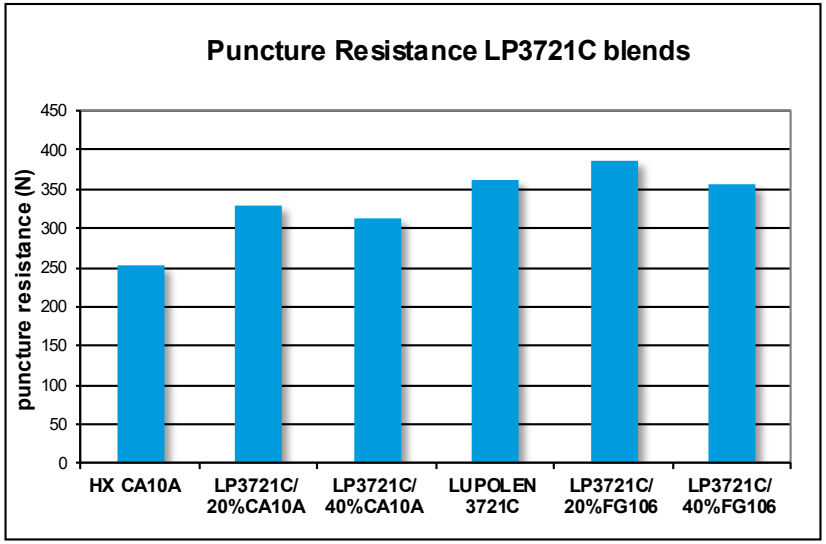




- The tear resistance decreases when adding *Hifax* CA10A with both HDPE and MDPE
- The difference is less visible with the addition of *Clearflex* FG106

Sheet characterization: Puncture resistance





- **The addition of *Hifax* CA10A has limited effect on puncture resistance with both materials HDPE and MDPE**

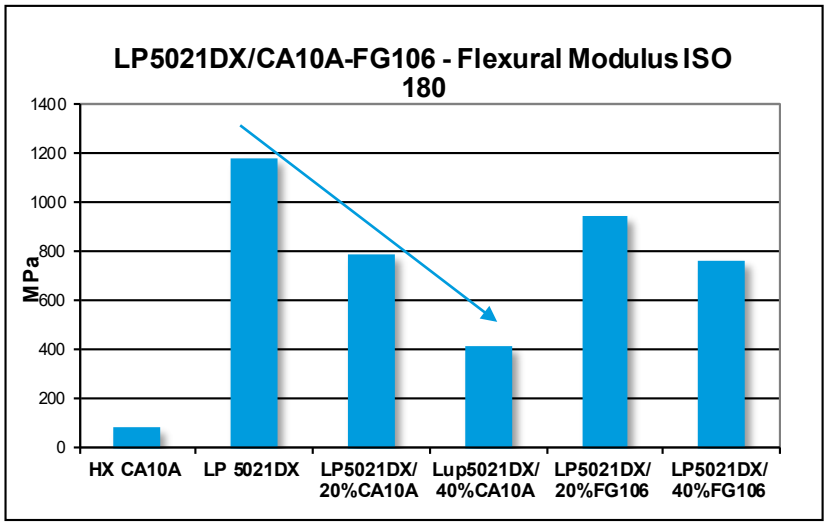
Plaque characterization

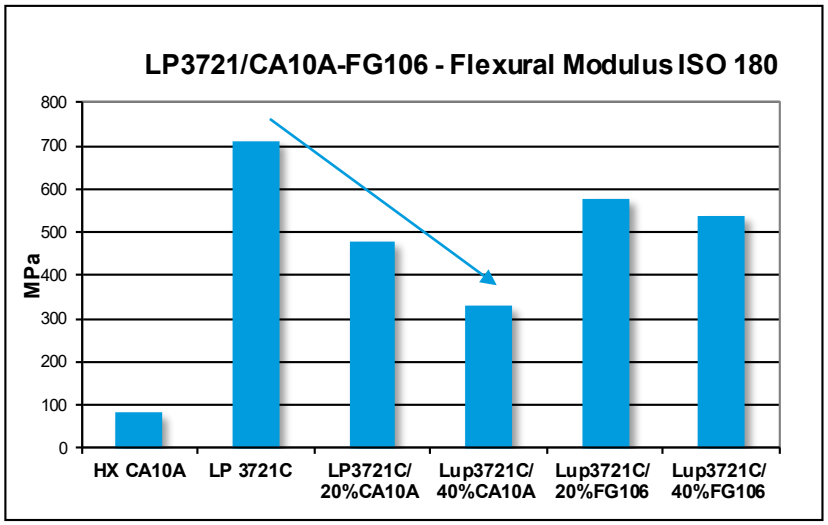
		HIFAX CA10A	LUPOLEN 5021DX	LP5021DX + 20% Hx CA10A	LP5021DX + 40% Hx CA10A	LP5021DX + 20% FG106	LP5021DX + 40% FG106
CLTE		**9**	**13.4**	13.5	13.7	17.7	15.3
VICAT - 9.81 N (24h)	° C	**55.2**	**125**	121	96	122	117

		HIFAX CA10A	LUPOLEN 3721C	LP3721C + 20% Hx CA10A	LP3721C + 40% Hx CA10A	LP3721C + 20% FG106	LP3721C + 40% FG106
CLTE		**9**	**14.5**	15.6	14.5	15.7	17.7
VICAT - 9.81 N (24h)	° C	**55.2**	**118**	111	91.5	116	112

- **The Coefficient of Linear Thermal Expansion (CLTE) of *Hifax* CA10A is very good (much lower) with respect to HDPE and MDPE but their blends do not show any improvement**
- **The Vicat softening temperature of the blends decreases as expected**

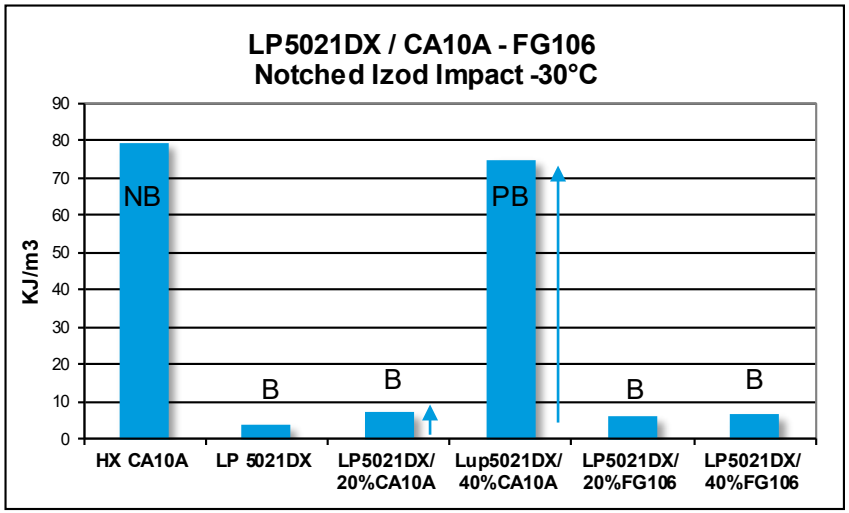
Plaque characterization: Flexural modulus

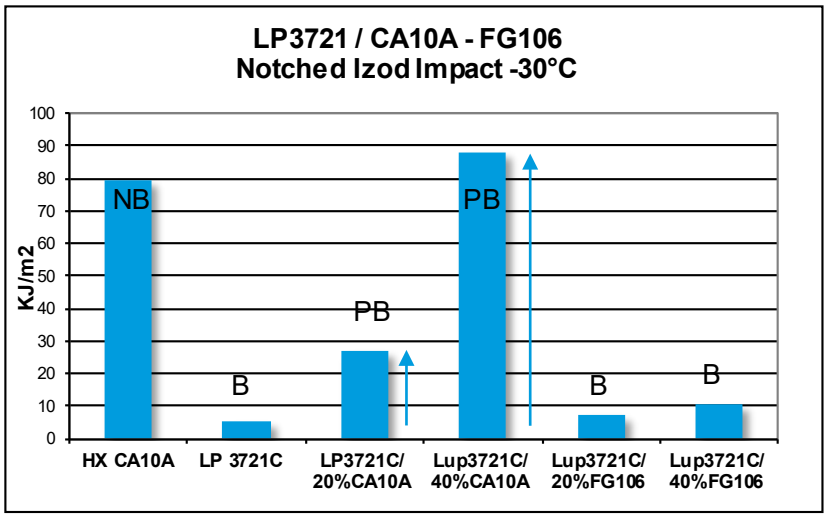




- The addition of *Hifax* CA10A significantly lowers the flexural modulus (greatly increases flexibility) in comparison to *Clearflex* FG106

Plaque characterization: Notched Izod impact





Impact Failure Mode
NB = No Break;
PB = Partial Break;
B = Break

- **The addition of *Hifax* CA10A @ 20% improves significantly the impact resistance at low temperature and drastically more @ 40% level**

ESCR and Weldability

Property	Test method	Unit	HX CA10A (fPP)	MDPE	HDPE	HDPE +20% fPP	HDPE + 40% fPP	HDPE + 20% LLDPE	HDPE + 40% LLDPE
ESCR (10% Igepal)	ASTM D 1693	Hours	> 1600	> 1600	52	> 1600	> 1600	740	> 1600
ESCR (100% Igepal)	ASTM D 1693	Hours	> 1600	> 1600	185	> 1600	> 1600	> 1600	> 1600

- **ESCR:**
  - Significant improvement observed in the ESCR of HDPE when blended with 20% *Hifax* CA10A (fPP)
- **Weldability:**
  - *Hifax* CA10A (fPP) can be successfully welded at lower temperatures and higher speeds than HDPE or MDPE (HDPE and MDPE showed adhesion failure when welded at 400°C, while fPP could be successfully welded at high speed even at 360°C)
  - The weldability window of HDPE seems improve significantly when blended with *Hifax* CA10A or LLDPE (HDPE could be successfully welded at 400°C when *Hifax* CA10A or LLDPE were added)
  - Typical HDPE welding conditions might have to be adjusted if *Hifax* CA10A or LLDPE is blended in as modifier

Weathering

Tensile Stress At Break Retention after QUV Weathering of *Hifax* CA10A (fPP), HDPE, HDPE / *Hifax* CA10A and HDPE / LLDPE Blends

Physical Property	Exposure Time (Hours)	Test Method	Unit	fPP	HDPE	HDPE + 20% fPP	HDPE + 40% fPP	HDPE + 20% LLDPE	HDPE + 40% LLDPE
Tensile Stress at Break	0	ISO 527	MPa	22.4	15.8	16.5	23.2	21.8	30.7
Tensile Stress at Break	500	ISO 527	MPa	21.3	16.3	14.9	24.6	17.3	32.8
Tensile Stress at Break	1000	ISO 527	MPa	20.3	16.6	14.7	19.8	16.0	17.0

Tensile Stress At Break Retention after QUV Weathering of *Hifax* CA10A (fPP), MDPE, MDPE / *Hifax* CA10A and MDPE / LLDPE Blends

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Tensile Stress at Break	0	ISO 527	MPa	22.4	32.4	24.8	24.7	32.3	29.5
Tensile Stress at Break	500	ISO 527	MPa	21.3	34.2	24.2	24.1	34.7	33.0
Tensile Stress at Break	1000	ISO 527	MPa	20.3	32.6	25.1	23.1	30.9	30.8

- **Accelerated QUV ageing results on 1mm thick sheet specimens using an ATLAS UV 2000 apparatus**

Summary

- The addition of *Hifax* CA10A (fPP) to either HDPE or MDPE provides following advantages:
  - Increased flexibility
  - Synergistic effect on tensile stress at break for HDPE / *Hifax* CA10A blends
  - Improved impact resistance at low temperature
  - Improved ESCR
- No improvement was observed on
  - CLTE (despite a much better performance of *Hifax* CA10A)
- Addition of *Hifax* CA10A also indicates an improvement during weldability tests although a more thorough study may be helpful to confirm these findings
- Finally, the accelerated UV weathering test shows that the introduction of *Hifax* CA10A does not have a negative effect on durability if a proper stabilization package is chosen

Hifax CA10A flexible polypropylene for geomembranes

***Hifax* CA10A flexible polypropylene (fPP) for geomembranes**

Agenda for *Hifax* CA10A flexible polypropylene for geomembranes

- *Hifax* CA10A technical data sheet
- Typical physical properties of *Hifax* CA10A in comparison with other materials used for making geomembranes (HDPE and PVC)
- *Hifax* CA10A accelerated weathering data
- Chemical resistance guidelines for *Hifax* CA10A
- Summary

Hifax CA10A for flexible sheet (barefoot additives package)

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Charpy Impact Strength - Notched			
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Hardness			
Shore Hardness, (Shore D, 15 sec)	30		ISO 868
Thermal			
Vicat Softening Temperature, (A50)	60	°C	ISO 306
Heat Deflection Temperature B, (0.45 MPa, Unannealed)	40	°C	ISO 75B-1, -2
DSC Melting Point	142	°C	ISO 11357-3
Optical			
Gloss, (60°, 45 mil)	85		ASTM D2457

Formulation package for *Hifax* CA10A based geomembranes

- *Hifax* CA10A contains a barefoot stabilization package and has to be considered as a building block for geomembrane formulations
- Typical formulations consist of at least:
  - *Hifax* CA10A (base resin)
  - Colorant Master-Batch
  - Primary and Secondary Antioxidants
  - UV Stabilizers
- LyondellBasell APS Masterbatches portfolio offers a black masterbatch for *Hifax* CA10A for a long lasting performance of the geomembrane. It is based on a combination of highly dispersed carbon black and a specific stabilizer package to meet the requirements of relevant standards such as GM18
- Masterbatch dosing levels are typically in the range 6 – 8% and tailor-made combinations can be considered
- Customers need to conduct their own tests and make their own determinations regarding the suitability of LyondellBasell resins for their specific end use applications

Hifax CA10A for flexible sheet

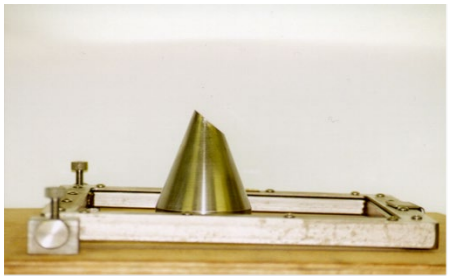
Typical physical properties of *Hifax* CA10A in comparison with other materials used for making geomembranes (HDPE and PVC)

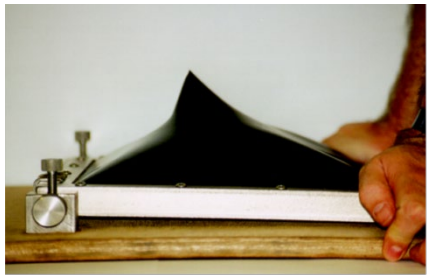
Typical physical properties in geomembrane applications

- Truncated Cone Puncture Resistance (ASTM D5514)
- Puncture Test (ASTM D4833)
- Multi-Axial Elongation Performance (ASTM D5617)
- Tensile Strength-Elongation (ASTM D5617)
- Flexibility (DMTA) and Impact
- Tear Resistance (ASTM D1004)
- Dimensional Stability (CLTE)
- Barrier Properties (ASTM D1434, ASTM E96) and ESCR
- Density (ASTM D972)

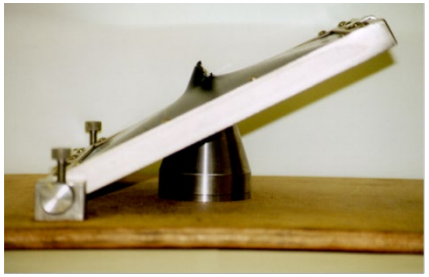
Critical Cone Height

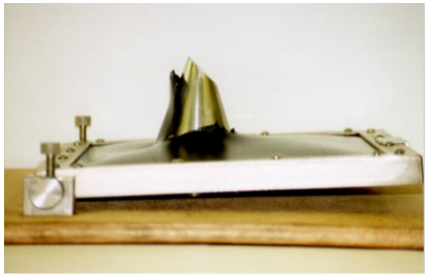
- Critical Cone Height is the maximum exposed height of a cone or pyramid that will not cause a puncture failure of a geosynthetic at a specified hydrostatic pressure for a given period of time.



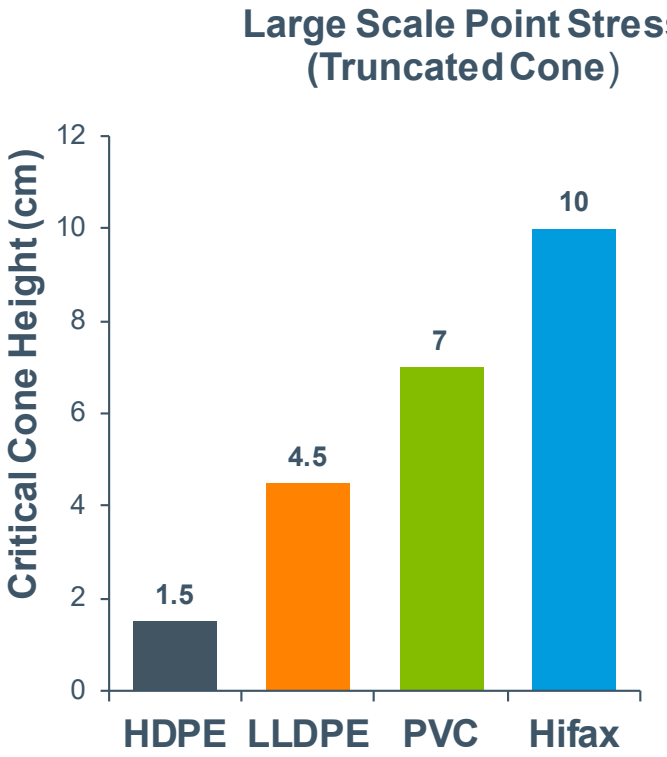


1mm *Hifax* CA10A





1mm HDPE

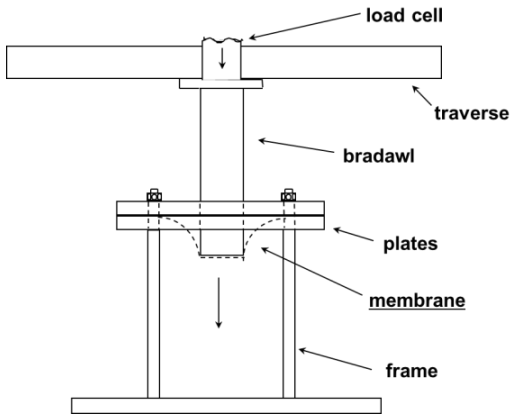


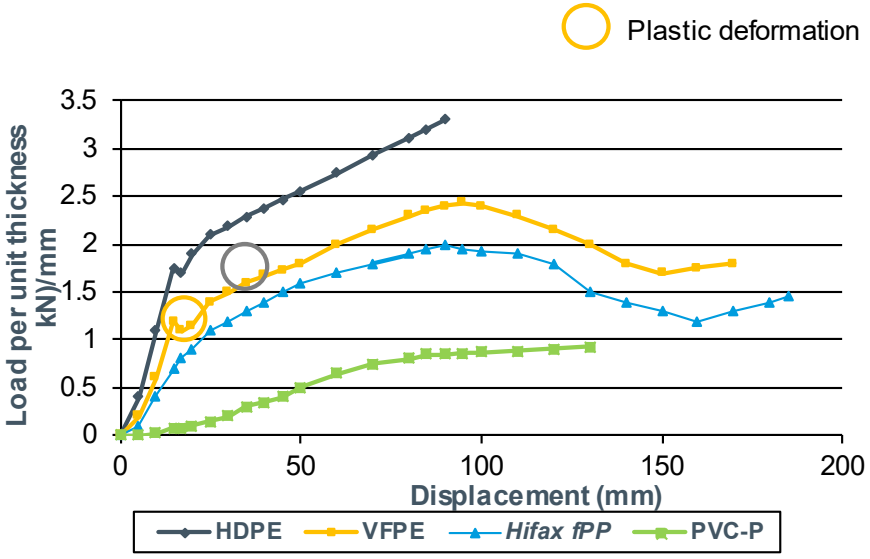
Typical materials used for geomembranes

***Hifax* CA10A shows maximum critical cone height in comparison to other materials**

Puncture Resistance Test (ASTM D4833)

- When tested according to ASTM D 4833, HDPE and MDPE show higher puncture resistance than *Hifax* CA10A (fPP), but it elongates much more than PE before being punctured therefore often providing an improved puncture resistance in the field
- *Hifax* CA10A deforms more (200 mm) than PVC (120 mm) and HDPE (yield at 20 mm)
- After 20 mm of deformation, LLDPE and HDPE yield; as a consequence, all stress is concentrated in a small area where necking occurs
- The entire surface of the sample of Hifax CA10A and PVC participate to the deformation process
- After bursting, *Hifax* CA10A and PVC recover most of the deformation, HDPE remains fully deformed

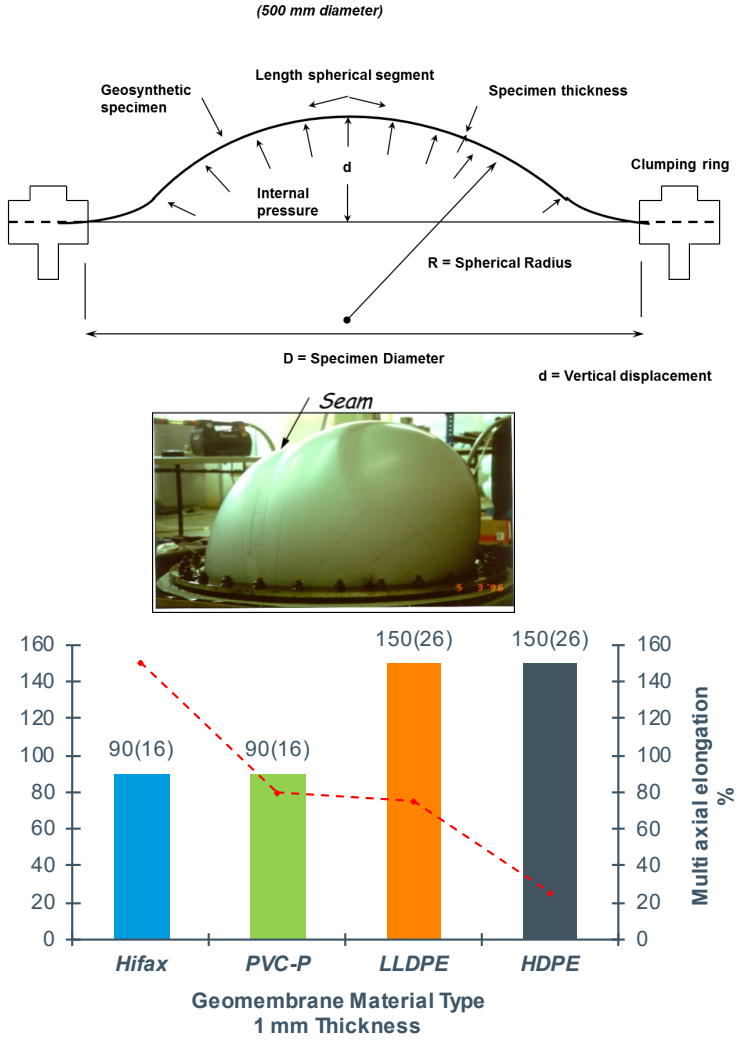




Hifax CA10A shows better elongation and hence improved puncture resistance on the field

Multi-Axial Elongation Performance (ASTM D5617)

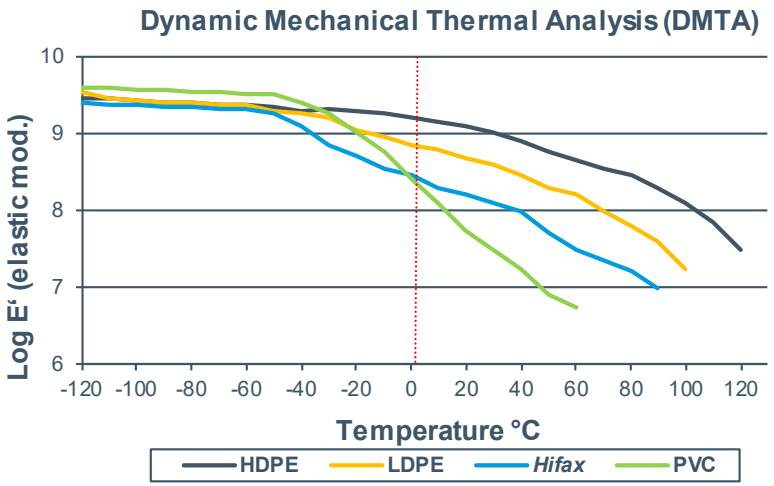
- Geomembranes produced from *Hifax* CA10A exhibit high extensibility, giving it high conformance characteristics
- *Hifax* CA10A does not show any yielding or necking. It deforms more than 200% (up to 450%) without rupture, even in the welded area
- Membranes fail with a “star” shaped rupture, that demonstrates even stress distribution

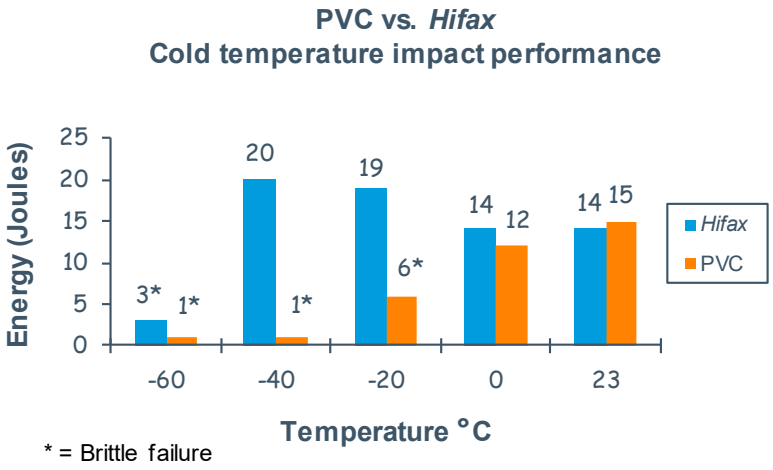


***Hifax* CA10A based geomembranes exhibit high extensibility**

Low temperature flexibility and impact performances (internal methods)

- *Hifax* CA10A shows superior flexibility at temperatures below 0°C, and it is the material of choice in cold environments
- *Hifax* CA10A deforms like PVC-P rather than absorbing energy like HDPE
- At low temperatures, PVC-P looses its deformation capacity
- Due to its low ductile/brittle transition temperature *Hifax* CA10A maintains its flexibility even at low temperature, and it can be installed in cold regions and in zones located at high geographic altitudes



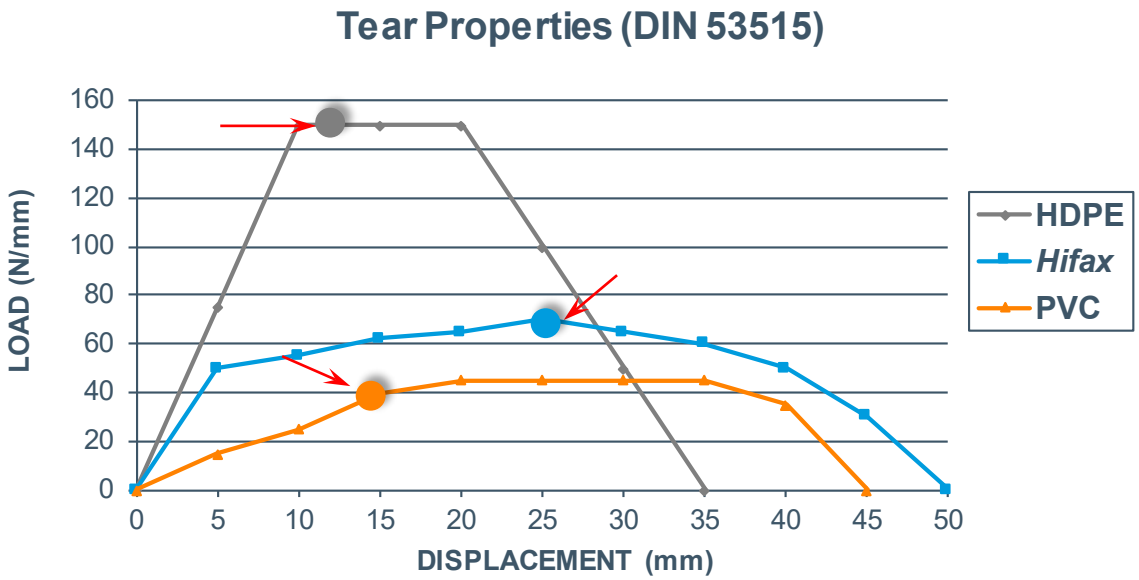


* = Brittle failure

***Hifax* CA10A shows superior flexibility in cold environments**

Tear Resistance - Graves Tear (ASTM D1004)

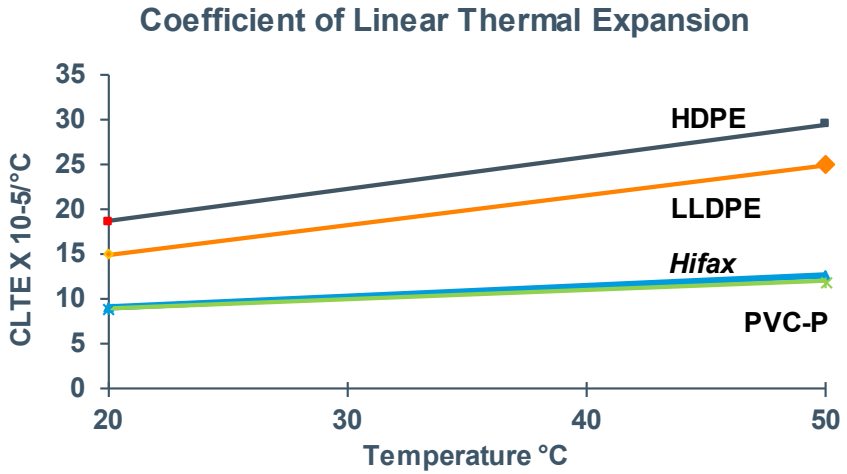
- High tear resistance is important to avoid rupture and limit the damage (propagation) when a crack is occurring in the sheet
- Elongation before crack initiation and propagation is more important than tear strength
- *Hifax* CA10A absorbs energy in plastic mode, and exhibits extensive deformation before crack initiation and propagation



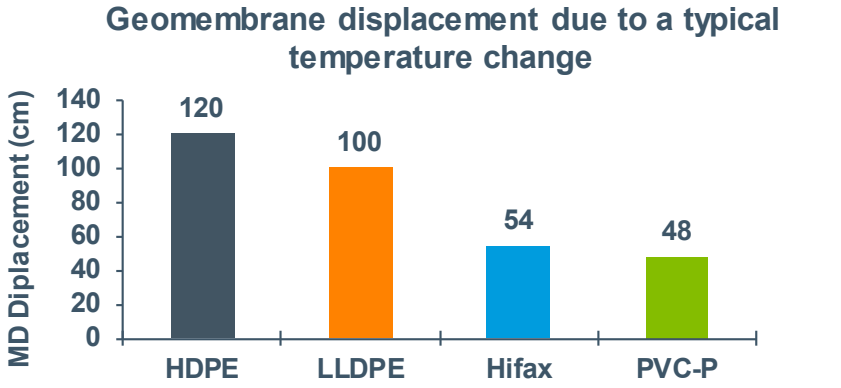
***Hifax* CA10A based geomembrane shows high tear resistance and limits damage**

Hifax CA10A based geomembrane dimensional stability

- A low CLTE allows to design and install liners with large total surface area without the need of controlling the effect of temperature changes (day-night, summer/winter) on dimensions
- It also decreases the risk of creasing due to dilatation, and stress due to thermal contraction/expansion
- PVC has the lowest CLTE, but it loses plasticizers with time
- *Hifax* CA10A has almost the same thermal expansion behavior as PVC, and the lowest CLTE among the polyolefins used in geomembranes (approximately half of HDPE)



Tested per ASTM D696 - Test performed on typical samples provided by our customers

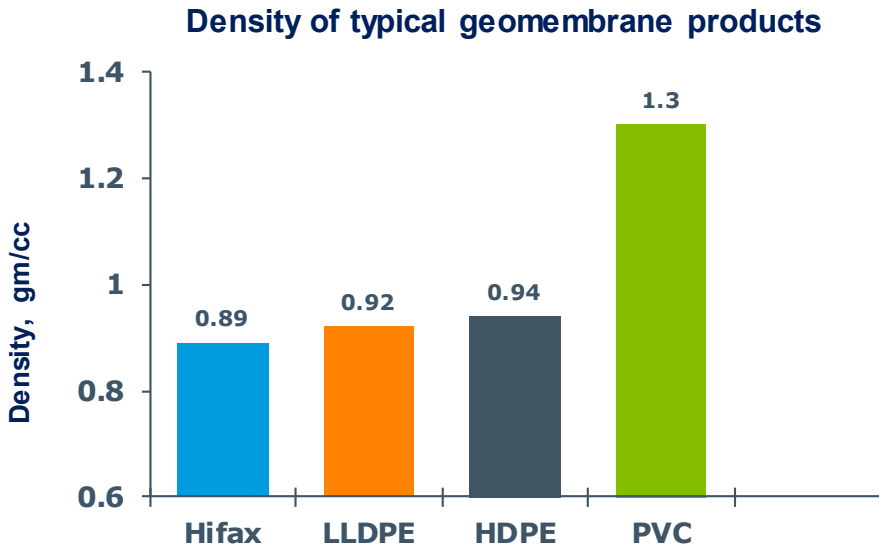


Displacement per 100 meter length of geomembrane when exposed to a 50°C temperature change (20°C - 70°C) *as calculated from CLTE given in previous graph*

Hifax CA10 based geomembrane shows good dimensional stability

Density (ASTM D 792) and Environmental Stress Cracking Resistance

- *Hifax* CA10A has very low density, that translates into less material needed for making the same membrane, with significant cost savings in large installations



- Due to its low crystallinity, *Hifax* CA10A does not show any sensitivity to Environmental Stress Cracking
- Example of ESCR test with *Hifax* CA10A

Test conditions:	**ASTM D 1693**
Test type:	**Bent Strip**
Igepal concentrations:	**10% and 100%**
Test temperature:	**20°C, 50°C, 95°C**
Test time:	**1500 and 3000 hours**
Results:	**No failures or visible cracking observed**

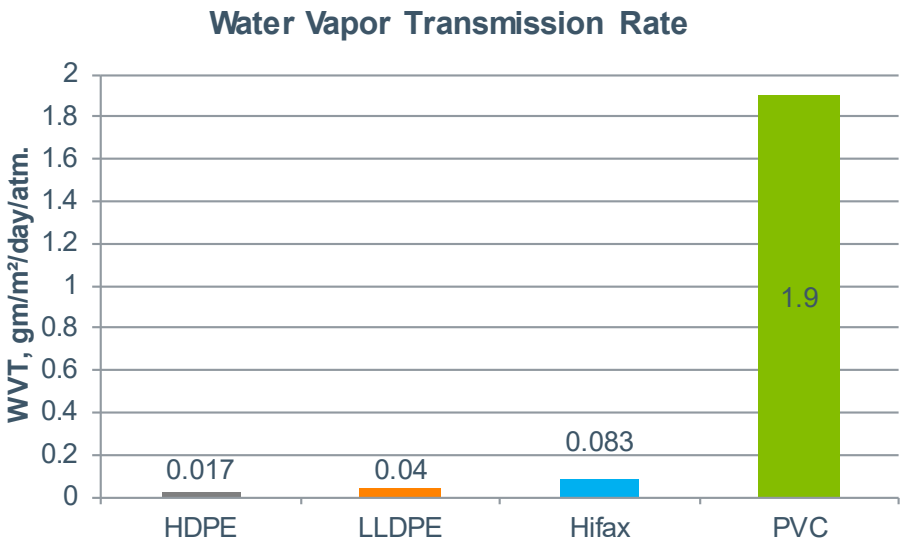
***Hifax* CA10A based geomembrane shows very good ESCR**

Barrier properties of *Hifax* CA10A based geomembrane

- Gas Permeability Characteristics (ASTM D1434)
- In landfill capping, membranes will have to retain gases (mainly methane and carbon dioxide) and evaporated solvents. *Hifax* CA10A enables effective gas and moisture barrier characteristics
- Water Vapor Transmission Rate (ASTM E96)

Gas	Value	Unit
Methane	80-90	cc/(m^2*day*atm)
Oxygen	320-350	cc/(m^2*day*atm)
Carbon Dioxide	1100-1250	cc/(m^2*day*atm)

Test Temperature: 23° C
Membrane Thickness: 1.12 mm



***Hifax* CA10A based geomembrane shows good barrier properties**

Comparison with PVC and HDPE

Benefits of *Hifax* CA10A vs PVC

- High flexibility without using plasticizers
- Significantly lower density
- Improved low temperature flexibility
- Better low temperature impact properties
- Improved tear and puncture resistance
- Higher UV resistance (if properly stabilized)

Benefits of *Hifax* CA10A vs HDPE

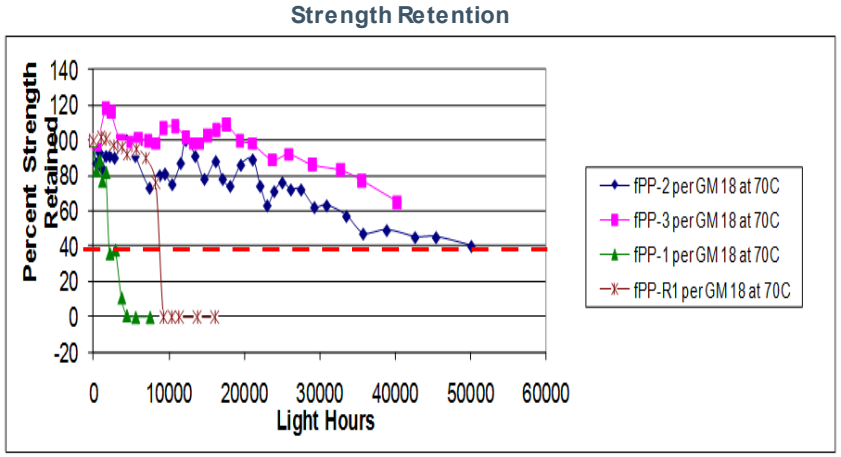
- Higher flexibility and ease of installation
- Less sensitive to Environmental Stress Cracking
- Higher dimensional stability (lower CLTE)
- Increased welding speed, wider seaming temperature window
- Higher puncture resistance
- Improved multi-axial stress-strain behavior
- Higher critical friction angle
- Higher Melting Temperature and temperatures resistance
- *Hifax* CA10A does not show necking phenomena

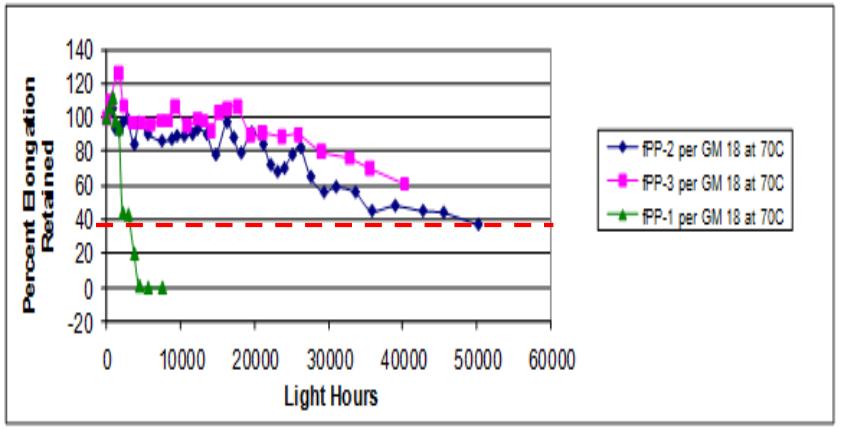
Hifax CA10A accelerated weathering data

- Accelerated weathering tests using heat aging ovens, Xenon-Arc weatherometers, and QUV devices are highly recommended to predict if the chosen formula will have the expected service life once exposed to the environment
- Comparing actual field UV exposure data and Lab UV exposure data for the same geomembrane it is possible to obtain the acceleration factor for the incubation device used in the Lab (QUV or Xenon Arc)

Hifax CA10A based geomembrane (fPP) accelerated weathering data

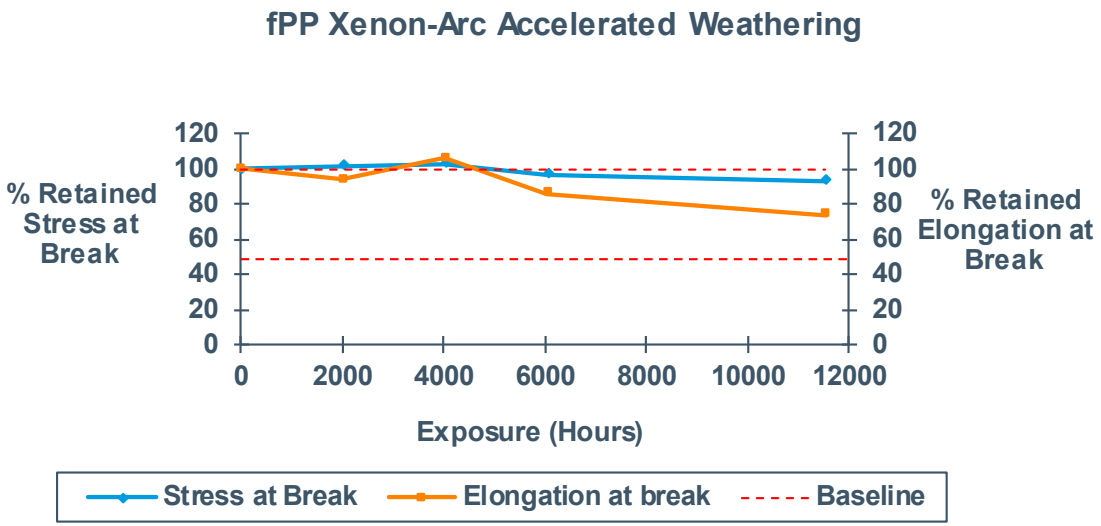
- Geosynthetic Research Institute (GRI) Standard GM18
- "Standard Specification for Test Methods, Test Properties and Testing Frequencies for Flexible Polypropylene Nonreinforced (fPP) and Reinforced (fPP-R) Geomembranes": New accelerated weathering requirement is based on physical property retention after either
  - UV-Fluorescent exposure per ASTM D7238/ G154 at 70°C or
  - Xenon Arc Exposure per ASTM D7238/ G155 at 80°C (new version of G26)
- G-154 Practice: QUV incubation data about 1 mm thick fPP geomembranes (GRI data)
  - Cycle = 20 hours UV at an un-insulated black panel temperature of 70° C alternating with 4 hours dark in condensation at an un-insulated black panel of 60°C
  - Irradiance Level = 0.78 W/(m2 nm) at 340 nm
  - Exposure Time = 20,000 light hours
  - Total Radiant Exposure = 56,160 KJ/m2 nm
  - Required tensile property retention after accelerated weathering = 50%





Hifax CA10A based geomembrane (fPP) accelerated weathering data

- Xenon Arc weathering test conducted per ASTM G26 on 1 mm thick *Hifax* CA10A unreinforced membrane containing 2.75% N-110 Carbon Black pigment and UV stabilizers (source: LYB)
  - Irradiance Level = 0.35 W/m2 at 340 nm (G155 = 0.70 W/m2 at 340 nm)
  - Cycle 690 min (11.5h) light followed by 30 min light + water spary on front surface sample
  - Black pannel temperature = 80°C, relative humidity = 50%
  - Total Radiant Exposure = > 15,210 KJ/m2 nm (6036h) acc. to G155
  - Required tensile property retention after accelerated weathering = 50%
  - Study stopped after approx. 12,000 hours of exposure



Hifax CA10A chemical resistance guideline

Chemical Resistance of *Hifax* CA10A against various classes of chemicals

Chemical Classes	Resistance
Acids Inorganic[1]	good resistance
Bases Organic[2]	good resistance
Bases Inorganic[3]	good resistance
Alcohols[4]	good resistance
Heavy Metals[5]	good resistance
Salts[6]	good resistance
Acids Organic[7]	marginal resistance*
Volatile/Semivolatile Organics[8]	marginal resistance*
Oil and Grease	marginal resistance*
Strong Oxidizers[9]	marginal resistance*
Aliphatic Halogenated Hydrocarbons[10]	Poor
Aromatic Halogenated Hydrocarbons[11]	Poor
Aliphatic Hydrocarbons[12]	Poor
Aromatic Hydrocarbons[13]	Poor

1. i.e. hydrochloric acid, nitric acid, sulfuric acid
2. i.e. amines
3. i.e. sodium hydroxide, calcium hydroxide, ammonium hydroxide
4. i.e. methanol, n-Propanol, Ethylene glycol
5. i.e. mercury, lead, cadmium
6. i.e. sodium chloride, potassium bromide, cupric sulfate, calcium carbonate
7. i.e. acetic acid, stearic acid
8. i.e. ketones, aldehydes, esters, amides, ethers, other oxygenated solvents
9. i.e. potassium permanganate, potassium dichromate, chlorine, perchloric acid, peroxides
10. i.e. trichloroethylene, methylene chloride, chloroform, or other chlorinated solvents
11. i.e. dichlorobenzene, other chlorinated solvents
12. i.e. butane, pentane, hexane, light petroleum ethers
13 i.e. benzene, toluene, xylene

* "Marginal Resistance" means *Hifax* CA10A is affected by some of these types of chemicals. Before using *Hifax* CA10A under these types of conditions, a sample of the specified material should be tested, with the actual chemicals, under actual or simulated service conditions.

It is important to note the degree of attack on any material is influenced by a number of variable factors, including concentration of the chemical, stress, temperature, aeration, velocity of flow, duration of exposure, possible chemical reaction with other compounds being held in the same impoundment, size of the test sample, etc. Therefore this information is only offered as a guide. It is suggested that a sample of the specified geomembrane be tested under actual or simulated service conditions.

Many polymers swell when exposed to concentrated organic chemicals. Based on laboratory data (ISO 175) *Hifax* CA10A would not be suggested for secondary containment of most hydrocarbons. For this reason, flexible polypropylene is not suggested for containment of:

1. Hazardous wastes with high concentrations of petroleum products.
2. Aromatic hydrocarbons
3. Chlorinated organic hydrocarbons

General recommendations

- Thickness of the membrane has a strong influence on long-term weathering, therefore do not apply data generated with a specific thickness to another thickness
- Pigment type, quality and concentration may affect UV and thermal stability, as well as potable water contact characteristics
- Too high processing temperatures or shear may degrade polymers and affect weathering and thermal stability
- Extra stabilization packages are likely to be necessary for specific processing or application conditions → LyondellBasell propose a Carbon Black masterbatch containing suitable stabilizer for long lasting performances
- It is strongly recommended to test the chemical resistance of the geomembrane against the specific chemicals that it will be exposed to.

Why customers use *Hifax* CA10A for geomembranes

- **Attributes**

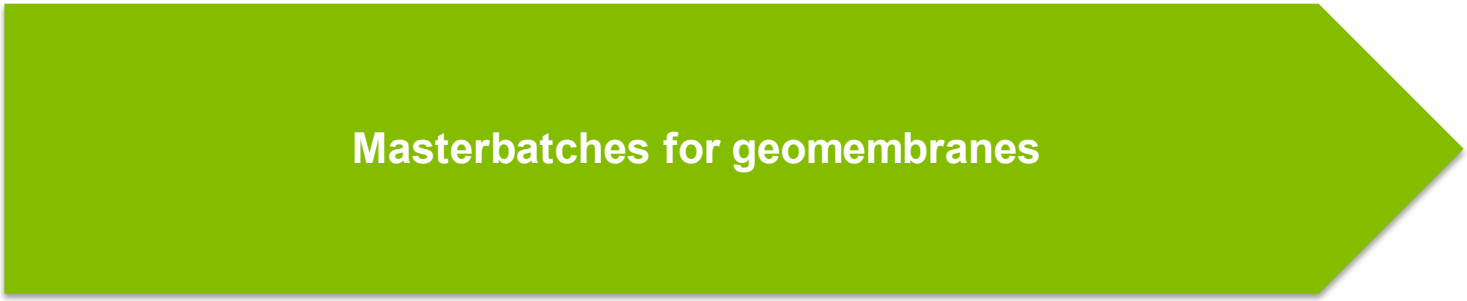
  - Flexible polypropylene with high rubber content
  - Flexible without plasticizers
  - Low specific gravity
  - Heat weldable on site
  - Excellent resistance to root and hydrostatic puncture
  - Formability to soil movements
  - Can be modified with UV stabilizers for excellent UV and thermal characteristics
  - High tear resistance
  - High chemical resistance

Summary: Main features of *Hifax* CA10A

- *Hifax* CA10A offers an outstanding balance of properties versus other materials used for geomembrane applications
- *Hifax* CA10A can be processed using all common technologies and has a wide seaming window allowing successful installation even under extreme weather conditions
- Tests should be performed to simulate application specific conditions prior to material selection

Flexible without plasticizers	Very good dimensional stability – low Coefficient of Linear Thermal Expansion	Low specific gravity	Excellent hydrostatic puncture, root resistance
High tear resistance	Outstanding resistance to multi-axial strain	Excellent low temperature flexibility	High critical friction angle
Formability to soil movements	Wide seaming temperature window	Excellent UV and thermal performance	Good Chemical and Environmental Stress Cracking Resistance

Masterbatches for geomembranes



Masterbatches for geomembranes

- Black masterbatches for Polyethylene
- Black masterbatch for *Catalloy* produced grades, like *Hifax* CA10A
- Conductive grades
- Grades with process additives to avoid die deposits and surface defects
- Color masterbatches for geomembranes
- Cool Color Masterbatches
- Grades for high Solar Reflectance Index (SRI)
- Additive masterbatches

Masterbatch vs Compounds

- **Masterbatch Advantages**

Cost advantages to customers	Ability to use single color concentrate into different end use resins or products
Quicker changeovers	Inventory concerns: rationalization of letdown resin for multiple colors
Warehouse space considerations	Reduced shipping costs

Black Masterbatches for geomembranes

Black Masterbatch

LYB black masterbatches are formulated for optimum dispersion, compatibility and distribution within the customer's base polymer and extrusion equipment.

Thermal Stabilization

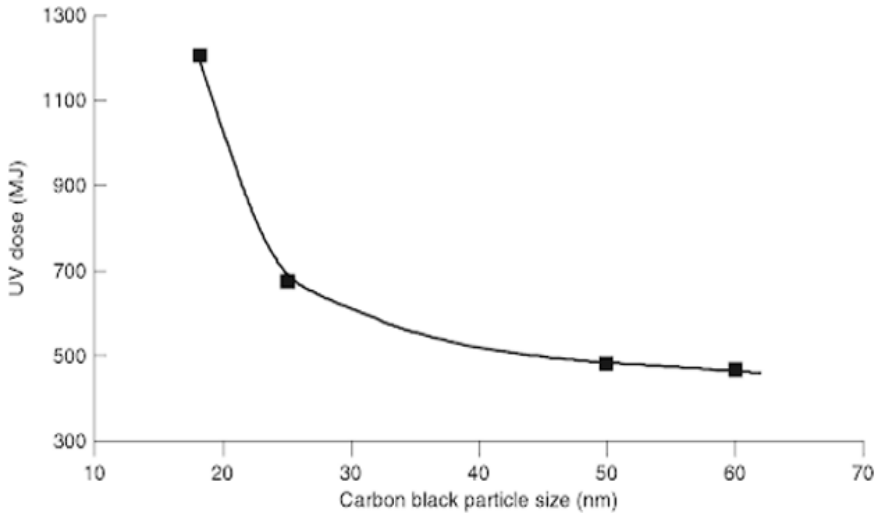
LYB masterbatches contain antioxidant packages that provide process and long term thermal stability. Oxidation induction time (OIT) values are used as a measure of thermal stability as requested by several major standards and testing Institutes.

HALS

HALS are sometimes used in polyolefin geomembranes because they exhibit multi-functional stabilization action and can protect the geomembranes against both heat and UV light.

Geomembranes and Carbon Black

- Carbon black acts as a UV screening agent and also performs a radical trapping function by binding up damaging free radicals
- Maximum effectiveness is achieved when a fine particle size is used and excellent dispersion is achieved
- P-type carbon black is normally used
- Levels of carbon black only up to 2.5–3.0% are used in HDPE since larger amounts can detract from the mechanical properties of HDPE



Failure point of a HDPE geomembrane under UV irradiation as a function of carbon black particle size. Note that the smaller the carbon black particle size, the greater the UV stability of the geomembrane

Geomembranes & Carbon Black Dispersion

- Effect of a poor carbon black dispersion on the performance properties of geomembranes

Effect	Comments
Reduced UV resistance	Localized regions that are deficient in carbon black or have large interparticle distances show increased sensitivity to UV degradation
Reduced stress crack resistance	Agglomerates of carbon black can act as stress concentrations and provide initiation sites for stress cracking
Reduced tensile properties	Agglomerates of carbon black can act as stress concentrations and provide initiation sites for fracture during tensile loading

HDPE Geomembrane Standards

LYB masterbatches are formulated to meet the requirements of the main geomembrane standards:

STANDARDS

- GRI-GM13 (USA & UK, Geosynthetics Research Institute)
- European standards: EN 13492, 13361, etc.
- Other national standards:
  - BAM (Germany's Federal Institute for Materials Research and Testing)
  - UNE (Spain), UNI (Italy), KIWA (Holland)

MAIN REQUIREMENTS

- Durability: Thermal and UV stability (Anti-Oxidants, HALS)
- Carbon black loading & dispersion
- Environmental stress cracking resistance (ESCR)
- Physical / Mechanical properties.
- Chemical resistance
- Permeability

Black Masterbatch for MDPE Geomembranes

Ref.	% Carbon black	Carbon black type	Carrier	AO system	Remarks	OIT @ 200 ºC	HP-OIT @ 150 ºC
PBK LD-32359	40	P	LDPE	--	Minimum stab level		
PBK LD-3548	40	P	LDPE	Phenolic	Low stab level	> 50 min	> 250 min
PBK LD-32395	40	P	LDPE	Phenolic	Medium stab level	> 140 min	> 300 min
PBK LD-32142	40	P	LDPE	Phenolic/phosphite	Very high stab level	> 200 min	> 400 min
PBK LD-32391	40	P	LDPE	Phenolic/phosphite	Contains process aid	> 30 min	> 220 min
PBK LD-32416	40	P	LDPE	Phenolic/phosphite /HALS	Very high stab level	250 min	> 1000 min
PBK LD-32418	40	P	LDPE	Phenolic/phosphite /HALS	Very high stab level	230 min	700 min

Dosing is normally 5-6%

Black Masterbatch for *Hifax* CA10A based geomembrane

Black Masterbatch for *Hifax* CA10A based geomembrane

- Highly concentrated black and additive system
- Designed to be added to a natural grade such as *Hifax* CA 10A
- Excellent carbon black dispersion level results in better color economy and additive consistency
- Combined carbon black + stabilization package simplifies operations and avoids dosing mistakes
- Addition rates are in general 5 – 7 %

Geomembranes: Coextruded versions and Conductive grades

Coextruded Geomembrane variations

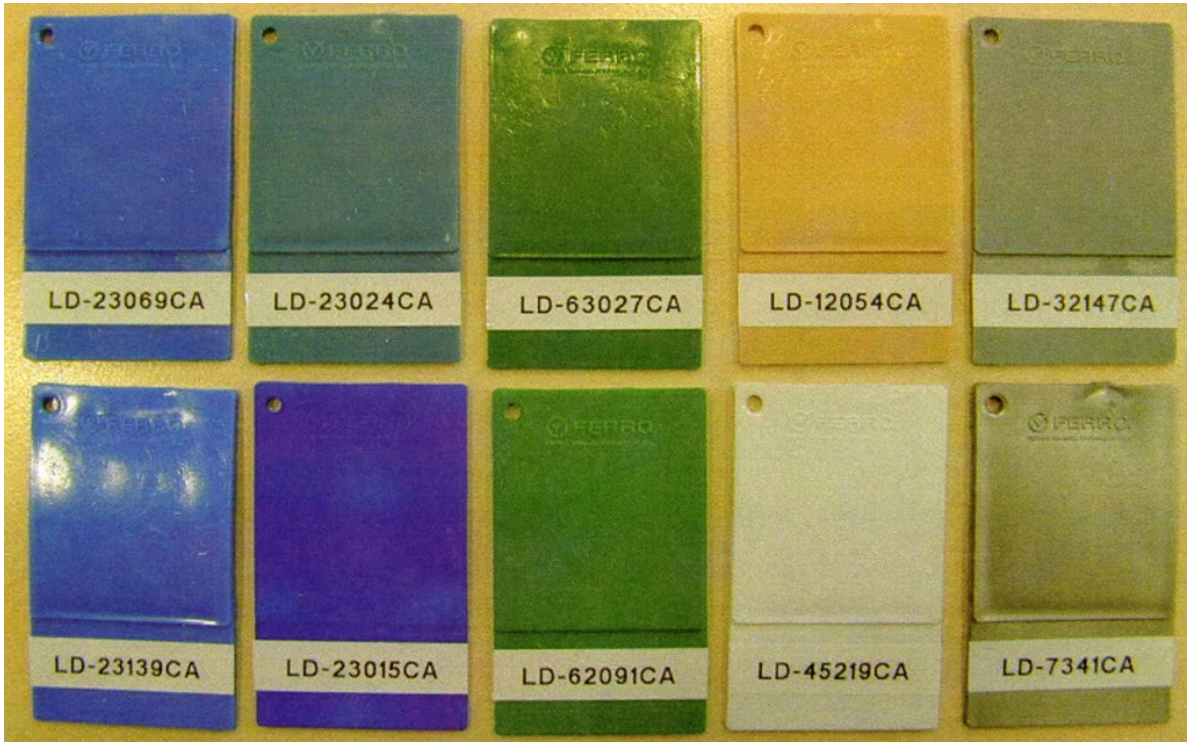
- Middle layers with high levels of electrically conductive carbon to facilitate spark testing
- White-surfaced top layers to reduce heat build-up, extend geomembrane lifetime and reduce desiccation (i.e. drying out) of the underlying clay
- Heavily stabilized top layers for long-term UV exposure applications

Conductive grades:

PBK PST SC 4B conductive compound

- Typically 100 micron layer with surface resistivity 10^4 ohm
- Used for in-line pin-hole detection systems. They work by holding an electric charge in a bar or wand at the location where the geomembrane passes over a metal roller. Pinholes or cracks in the geomembrane will automatically transmit a visible spark from the charged undersurface and set off an audible alarm

Color Masterbatches for Geomembranes



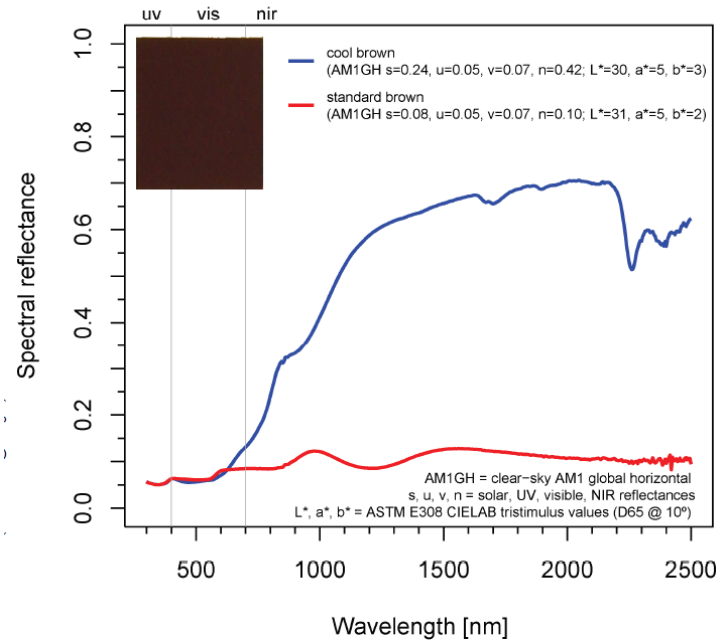
Based on very high stability inorganic pigments

High concentrations of UV additives and antioxidants

Cool Color Masterbatches

- Concentrates of special pigments which reflect IR radiation to a great extent, whereas carbon black and other pigments absorb almost all the IR
- Excellent heat and weathering resistance, lightfastness and opacity
- Several advantages result from this fact:
  - Lower temperature
  - Lower thermal expansion and contraction
  - Increased service life

cool colors reflect selectively



High Solar Reflectance Index (SRI) - Geomembranes

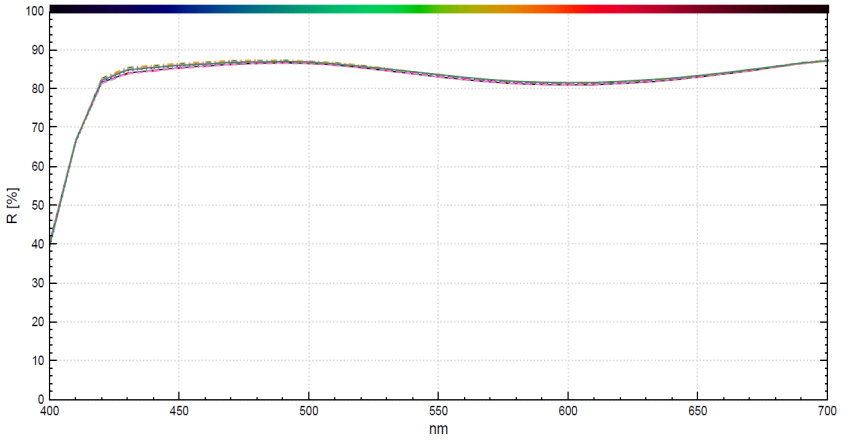
- Roof Geomembranes to meet reflection standards such as the US Green Building Council's Leadership in Energy and Environmental Design™ (LEED®)

- Advantages:
  - Reduce local air temp (urban heat island effect)
  - Reduce energy consumption & carbon emissions
  - Extend roof service life

- PWI LD-45219CA
  - UV stabilized White masterbatch
  - Excellent weather stability
  - Dosing 5% on HDPE

Minimum Solar Reflectance Index Value, by Roof Slope				
Slope		Initial SRI		3-Year Aged SRI
Low Sloped Roof	</=2:12	82	OR	64
Steep Sloped Roof	< 2:12	39		32

Solar Reflectance Index (SRI) is calculated from solar reflectance and thermal emittance values



Geomembranes – Additive Masterbatches

A wide variety of additive masterbatches is available:

- Antioxidants
- UV stabilizers
- Processing Aids
- Antiblocks
- Slip Agents
- Tailor-made blends

Testing of geomembranes

Technical Capabilities:

- LYB is fully equipped to carry out a wide variety of tests and evaluations in their Technology Centers and Laboratories
- Molecular analysis
- Element analysis
- Physical & Mechanical Properties
- Dispersion Tests
- Accelerated Weathering
- Extrusion equipment
- Thermal analysis
- Microscopy
- Rheology
- Optical properties
- Electric properties

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