Overview of Polyethylene used in 600 volt Underground Secondary Cable

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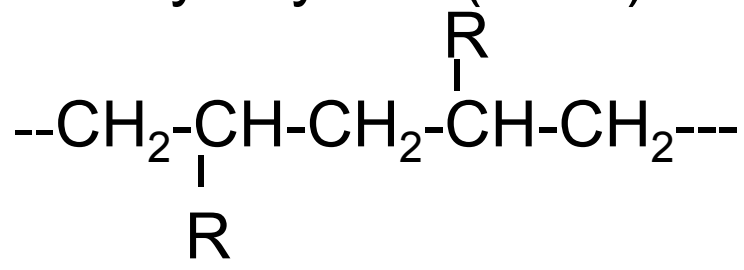
Presentation Outline

- Polyethylene Overview
  - thermoplastic PE
  - crosslinked PE
- Processes to Crosslink Polyethylene
- Recent advances in Moisture Crosslinkable Polyethylene

What is Polyethylene ?

Ethylene (Gas)

$CH_2=CH_2$ —Polymerization→ Polyethylene (Solid)

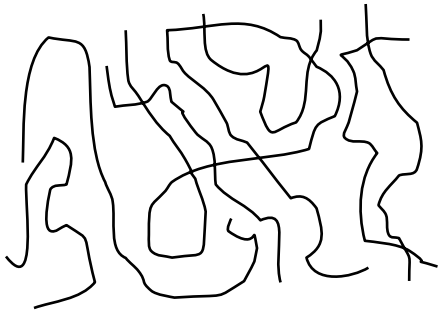


R represents branches

R = H, CH_3, CH_2-CH_3,.....

Polyethylene is composed of

Crystalline Region + **Amorphous Region**

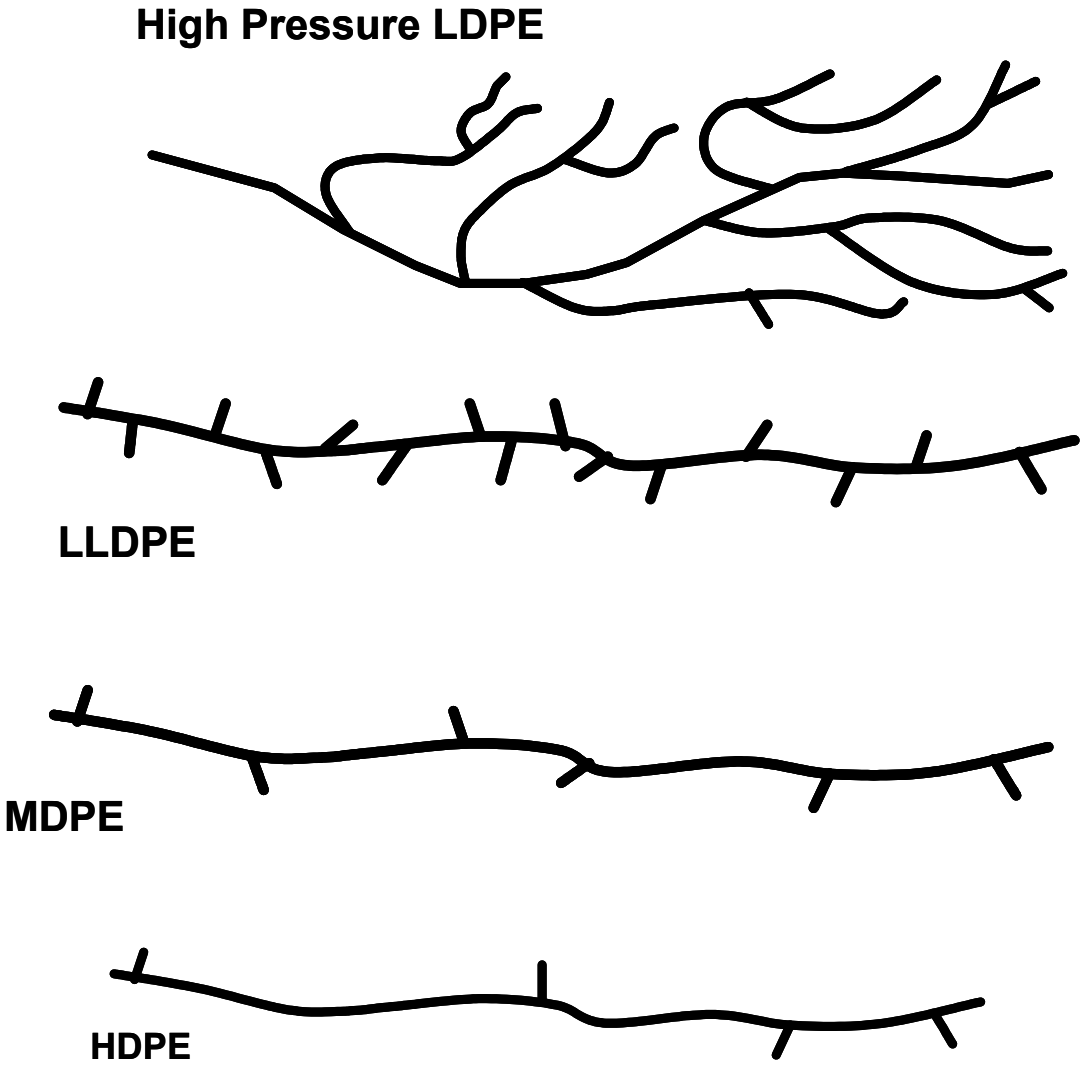


Polymerization Processes Used for Wire and Cable Polyethylene

High Pressure Reactor

Low Pressure Reactor

- Gas Phase
- Solution
- Slurry

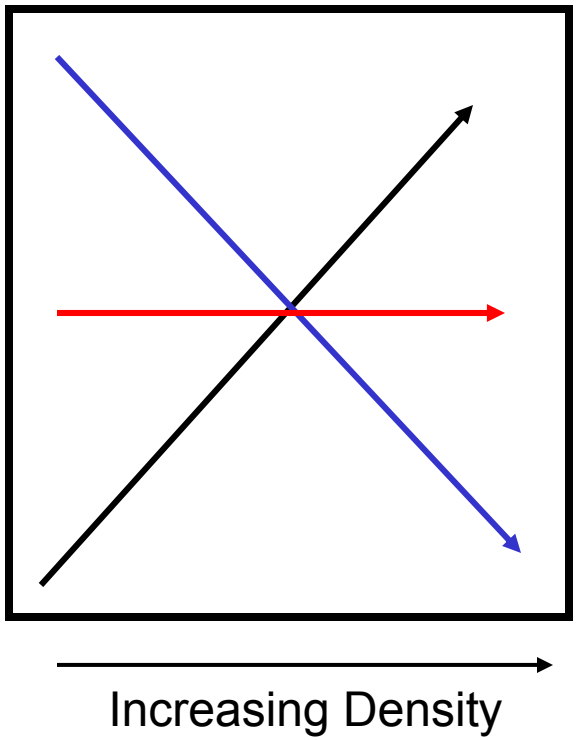


Polyethylene Density

Density => correlates to the crystalline content

Polyethylene Description	ASTM D1248 Type Classification	Density Range (gm/cm3)	Softening Range (°C)
ULDPE or VLDPE	0	< 0.910	90 to 115
LLDPE/LDPE	I	0.910 to 0.925	105 to 120
MDPE	II	> 0.925 to 0.940	120 to 130
HDPE	III	> 0.940 to 0.960	127 to 138
HDPE	IV	> 0.960	127 to 138

Polyethylene Density Affects Properties



Rigidity
Hardness
Abrasion Resistance
Chemical Resistance
Tensile Yield Strength
Haze

Electrical

Tear Strength
Impact Strength
ESCR
Permeability
Elongation
Shrinkage

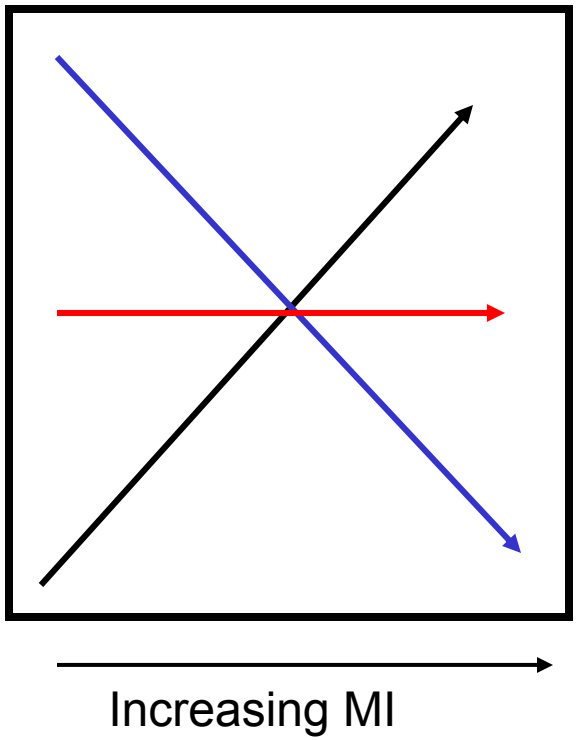
Polyethylene Melt Index

Melt Index => correlates to the polymer chain length

Melt Index	Polymer Chain Length	Viscosity
High	Short	Low
Low	Long	High

ASTM D1248 Category	Nominal Flow Rate (MI, g/10 min)
1	> 25
2	> 10 to 25
3	> 1.0 to 10
4	> 0.4 to 1.0
5	0.4 max

Polyethylene Melt Index Affects Properties

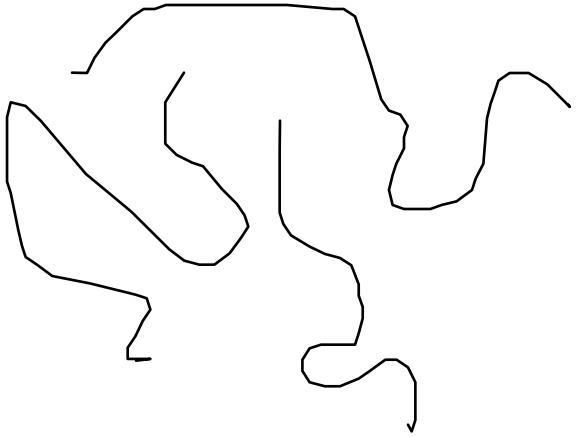


Processability
Shrinkage

Electrical

Tear Strength
Impact Strength
Tensile Strength
ESCR
Elongation

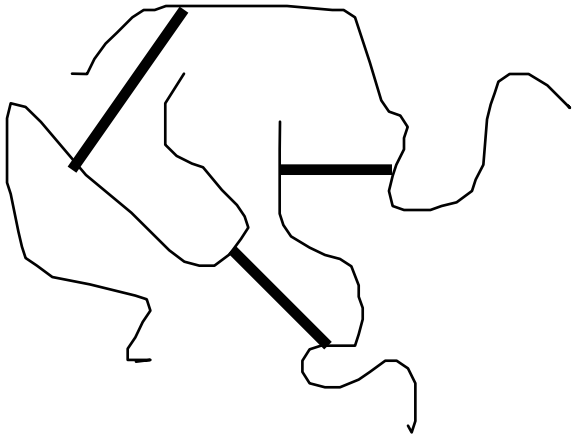
What is Crosslinked PE? (XLPE)



Polyethylene is many long, but still separate molecules.

Will melt and flow.

Crosslinking attaches these long molecules together.



Material will no longer melt and flow because molecular weight is too high.

Why Crosslink? To improve mechanical properties at high temperature (90C rating vs. 75C rating)

Methods to Crosslink Polyethylene

Free Radical

Peroxide

Electron Beam/Irradiation

Silane "Moisture Cure"

Monosil type - silane grafted to PE in the cabling extruder

Sioplas type - silane grafted to PE in a compound mixer prior to cable extrusion

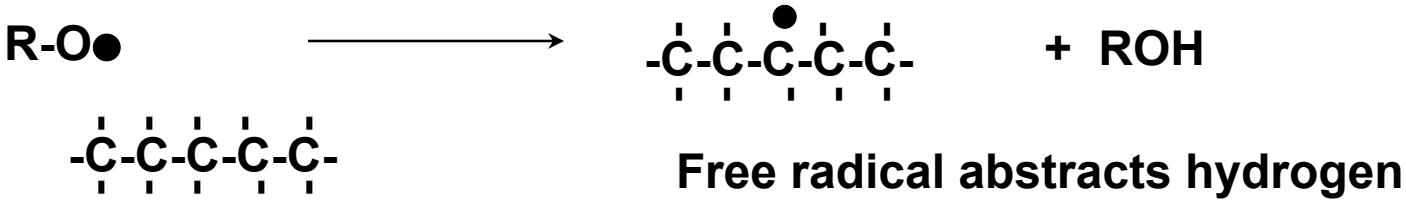
Reactor copolymer - silane copolymerized with ethylene into the polymer backbone in reactor

Peroxide Crosslinking Chemistry

1- Initiation

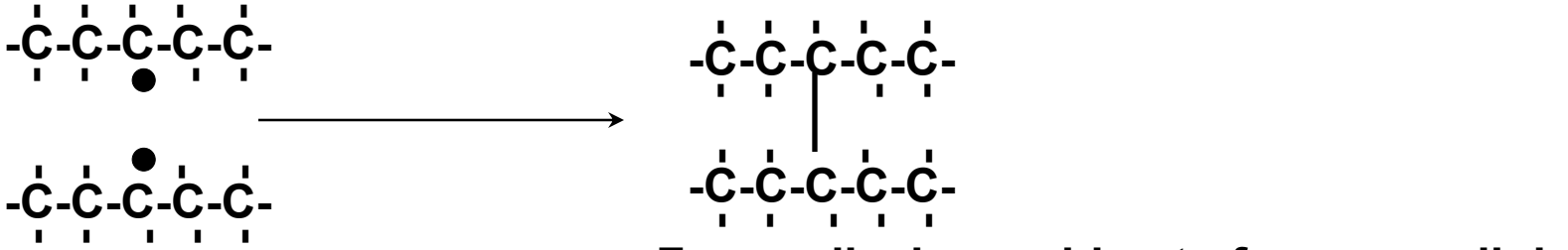
Peroxide decomposes to form free radicals

2- Propagation



Free radical abstracts hydrogen from polyethylene

3- Termination



Free radicals combine to form crosslink

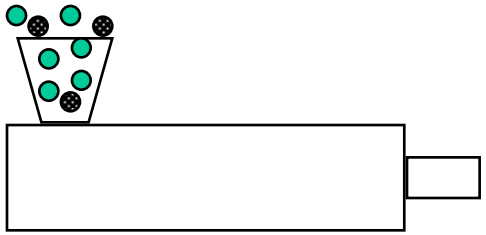
Crosslink is C-C bond

Moisture Cure Crosslinking Chemistry

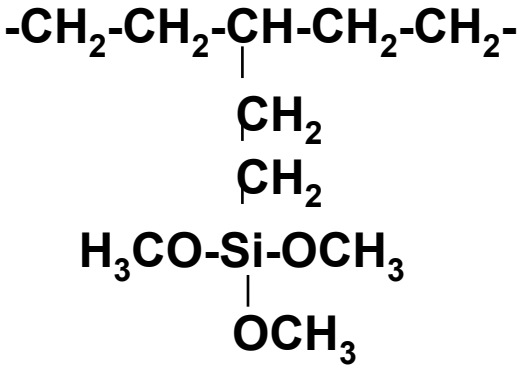
Monosil & Sioplas

Crosslinkable silane groups are added <u>AFTER</u> polymerization

Polyethylene
Peroxide
Silane

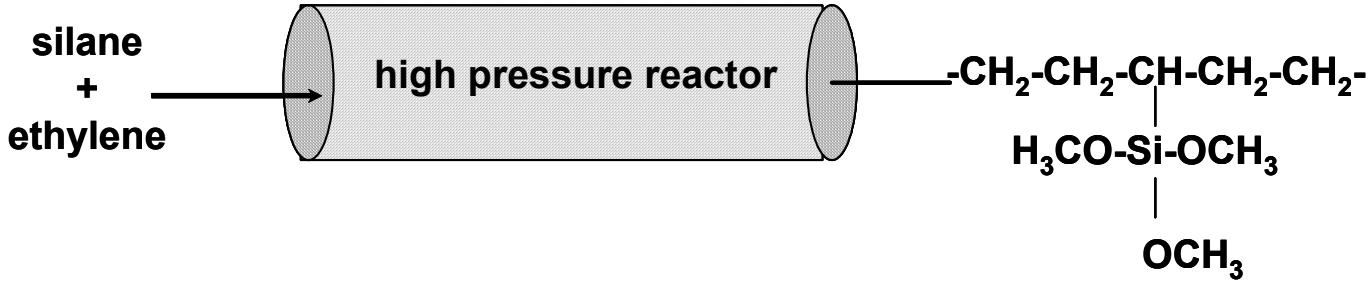


Grafted Resin



Reactor Copolymer

Crosslinkable silane groups added <u>DURING</u> polymerization



Moisture Cure Crosslinking Chemistry (cont'd)

Comparison Polyethylene Crosslinking Methods

CV Process Peroxide Cure

Advantages

- One compound into extruder
  - no need to mix materials or chemicals
- Insulation is cured when it exits the process
- Uniform crosslinking

Disadvantages

- Capital cost of CV equipment is high
- Limited extrusion speed to avoid scorch
- Extrusion speed can be limited by residence time in CV tube
- Scrap rates are higher

Moisture Cure Process

Advantages

- Low capital investment for cable line
- Fast extrusion and line rates
- Scorch less of a concern

Disadvantages

- Crosslink the insulation "off-line" in heated water bath
  - capital cost for large cable constructions could be high
- Extruder needs to mix materials

Moisture Crosslinking Process Comparison

Monosil

Advantages

- Flexibility in selecting commodity base resins
- Cures rapidly

Disadvantages

- Need to handle and dispose of liquid chemicals
- Using extruder for grafting and coating wire has a significant learning curve
  - Requires special extruder
- Material can be scorchy

Sioplas

Advantages

- No need to handle liquid chemicals
- Flexibility in selecting base resins
- Cures rapidly

Disadvantages

- Shelf life less than 6 months
- Material can be scorchy
- Can require drying before extrusion

Silane Reactor Copolymer

Advantages

- No need to handle liquid chemicals
- Long shelf life
- Minimal scorch

Disadvantages

- Need specific polymer
- Slightly slower cure rate than grafted resin
- Can require drying before extrusion

Recent Advances in Moisture Cure Material Technology

- Scorch resistant reactor silane copolymers
- Faster crosslinking catalysts for reactor silane copolymers
  - improved cure at ambient and accelerated (sauna) cure conditions
  - crosslinking rates comparable to Monosil/Sioplas
- HDPE with improved processing and mechanical properties