IEEE POWER ENGINEERING SOCIETY
CHICAGO CHAPTER

- **THE OKONITE COMPANY**
- **WEDNESDAY**
- **JANUARY 11, 2006**

- **JIM FITZGERALD**

ENGINEERING LINGO

WHEN YOU HEAR AN ENGINEER SAY

A NUMBER OF DIFFERENT APPROACHES ARE BEING IMPLEMENTED

It Means

ENGINEERING LLINGO

WE HAVEN'T A BLOODY CLUE ABOUT WHAT WERE TALKING ABOUT!!

ENGINEERING LINGO

When You Hear An Engineer Say:

Preliminary Operational Costs Were Inconclusive

It Means

ENGINEERING LINGO

The @#$% Thing
Blew Up
When I Flipped
The Switch

ENGINEERING LINGO

…and lastly, when you hear an engineer say:

The Test Results
Were Extremely Gratifying

It Means

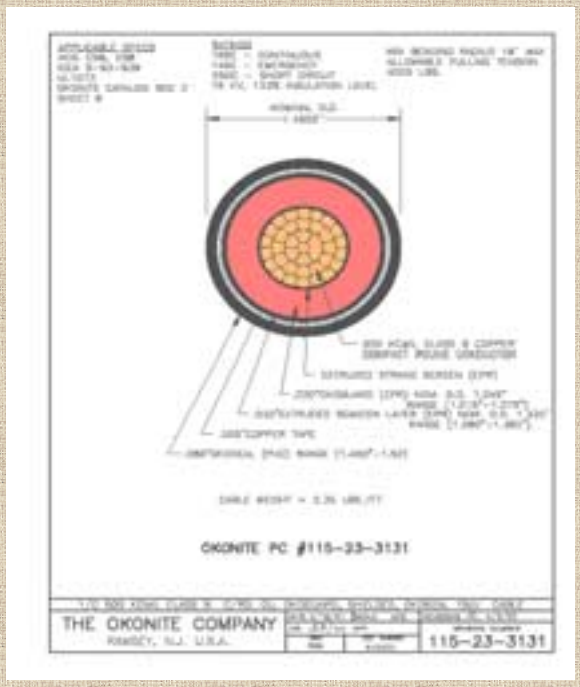
ENGINEERING LINGO

Thank God,
The Stupid Thing
Worked

AGENDA

- **INDUSTRY STANDARDS**
- **MEDIUM VOLTAGE CABLE DESIGN**
- **CABLE MANUFACTURING PROCESSES**
- **QUALIFICATION AND ROUTINE PRODUCTION TESTING**

MEDIUM VOLTAGE CABLE COMPONENTS

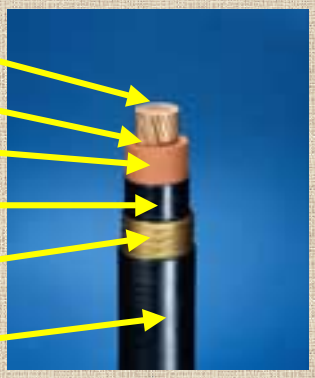


INDUSTRY STANDARDS

- **ICEA** - **INSULATED CABLE ENGINEERS ASSOCIATION**
- **AEIC** - **ASSOCIATION OF EDISON ILLUMINATING COMPANIES**
- **UL** - **UNDERWRITERS LABORATORY**
- **ASTM** - **AMERICAN SOCIETY FOR TESTING AND MATERIALS**
- **CUSTOMER PROJECT SPECIFICATIONS**

CABLE COMPONENTS

- Conductor
- Semi-conducting Strand Screen
- Insulation
- Semi-conducting Insulation Screen
- Metallic Shield
- Protective Covering
  - Jacket / Armor



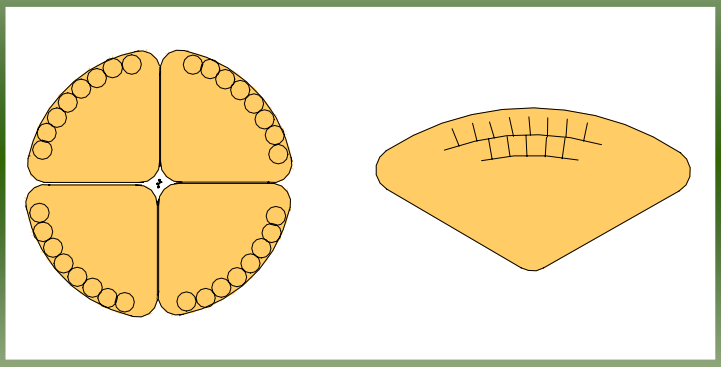
CONDUCTOR PURPOSE

DEFINED RESISTANCE

Conductors

- Copper or Aluminum
  - Cu 100% Conductivity
  - Al 61% Conductivity
- Shapes
  - Concentric
  - Compressed
  - Compact
  - Sector
  - Segmental

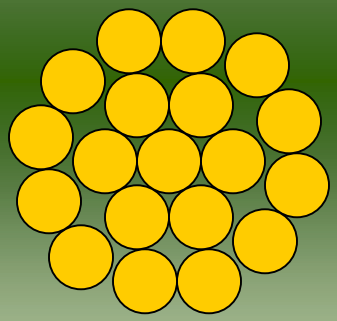
Conductors



Segmental

Sector

Conductors - Stranding

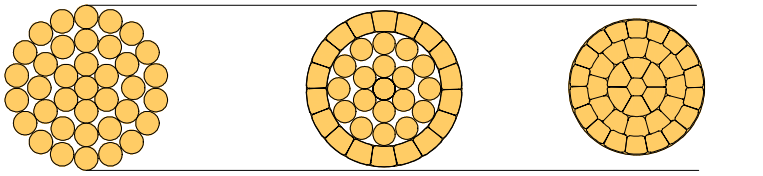


1

1 + 6 = 7

1 + 6 + 12 = 19

Conductors



STRAND DIMENSIONS

- CONCENTRIC = 100%
- COMPRESSED = 97% CONCENTRIC
- COMPACT = 93% COMPRESSED
- COMPACT = 90% CONCENTRIC

Conductors – ASTM Standards

Copper Standards

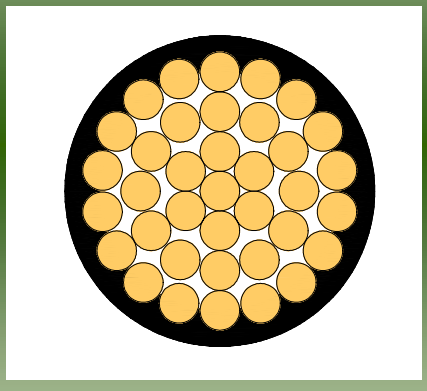
- B 3 Soft or Annealed Copper Wire
- B 8 Concentric-Lay-Stranded Copper Conductors, Hard Medium-Hard, or Soft
- B 33 Tinned Soft or Annealed Copper Wire for Electrical Purposes
- B 496 Compact Round Concentric-Lay-Stranded Copper Conductors

Conductors – ASTM Standards

Aluminum Standards

- B 233 Aluminum 1350 Drawing Stock for Electrical Purposes
- B 231 Concentric-Lay-Stranded Aluminum 1350 Conductors
- B 609 Aluminum 1350 Round Wire, Annealed and Intermediate Tempers, for Electrical Purposes
- B 800 8000 Series Aluminum Alloy Wire for Electrical Purposes – Annealed and Intermediate Tempers
- B 400 Compact Round Concentric-Lay-Stranded Copper Conductors

Conductor Screen



Conductor Screen

Cables rated 5 kV and above

Purpose: To reduce voltage stress at the interface between the conducting and insulating components

A cylindrical, smooth surface between the conductor and insulation

Insulation – Chief Purpose

To withstand the electrical field applied to the cable for its design life in its intended installed environment

Normal and Emergency Voltage and Current

XLP & EPR

- 1955 GE and peroxide cure polyethylene
- 1962 First EPR available

Insulation – Typical Materials

- **Ethylene Propylene Rubber (EPR)**
- **Crosslinked Polyethylene (XLPE)**

WALL THICKNESSES

	15 kV	25 kV	35 kV
100 %	175 mils	260 mils	345 mils
133 %	220 mils	320 mils	420 mils
173 %	260 mils	460 mils	650 mils

Shielding

- To confine the electrical field within the insulation.
- To reduce the chance of electrical shock when properly grounded
- To provide a symmetrical distribution of voltage stress
- To prevent surface discharge
- To reduce electrical interference
- To monitor voltage

Shielding

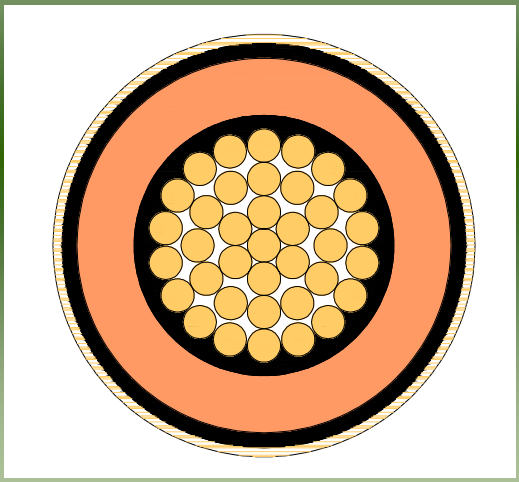
- **Components**
  - **Non-metallic semiconducting layer**
  - **Metallic layer**

Insulation Screen

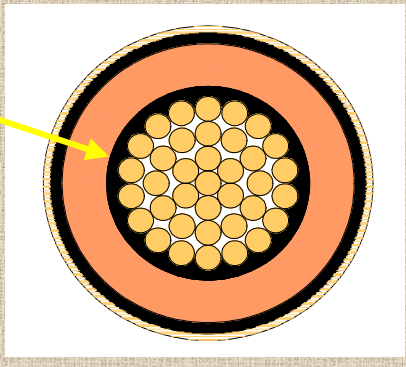
Purpose: To reduce voltage stress at the interface between the conducting and insulating component

A cylindrical, smooth surface between the insulation and shield

Insulation Screen



- **MAXIMUM ELECTRICAL STRESS**
- $$S = \frac{KV}{(d/2)Ln\,(D/d)}$$



Semiconducting layers (conductor and insulation screens)

- Extruded
- Electrical conductivity requirement at room and elevated temperature
- ICEA volume resistivity stability requirement

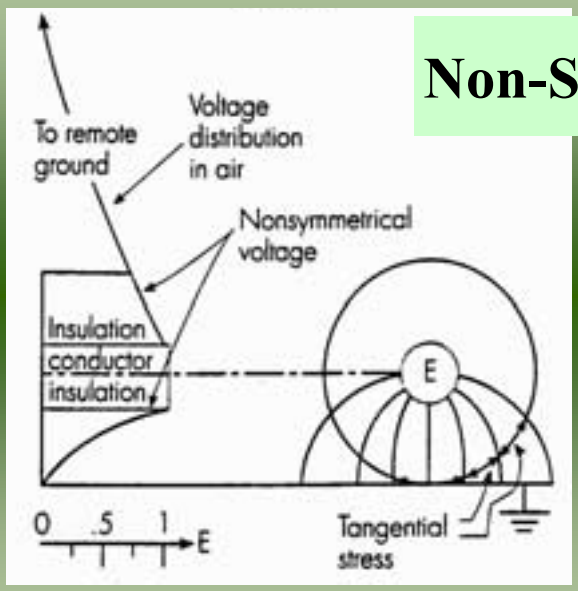
Shielding - Types

- Flat copper or bronze tape
- Corrugated copper or bronze tape
- Concentric applied copper wires
- Lead sheath
- Corrugated aluminum sheath
- Aluminized Polyester tape

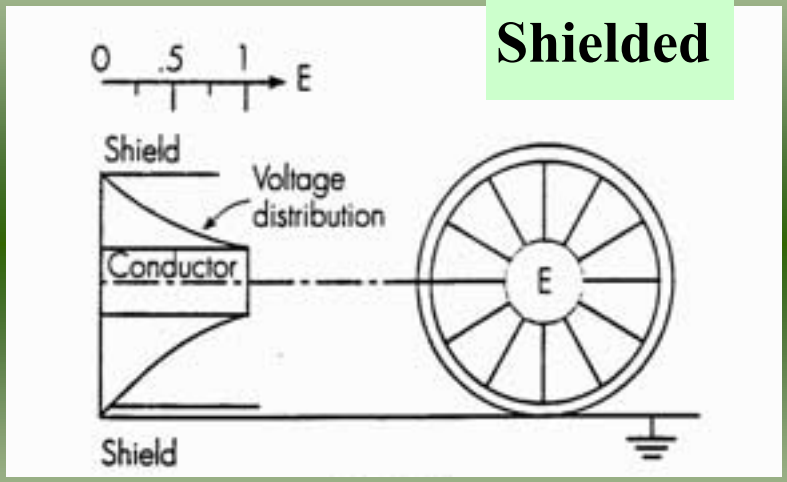
Shielding

Shielding

Non-Shielded



Shielded



Protective Coverings

- Metallic Armor
  - Interlocked Armor
  - Continuously welded corrugated armor (CLX)
  - Galvanized steel wires
- Jackets (non-metallic covering)
  - Cable Jackets

Cable Testing

- Factory Production Tests
- Qualification Tests
- Defined by ICEA & UL standards and customer specification

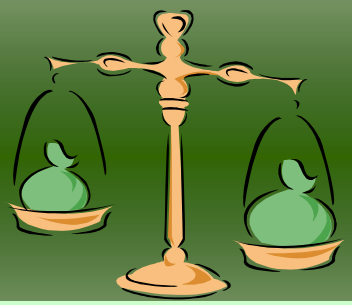
Cable Testing - Factory

- Conductor Resistance
- Insulation
  - ac Withstand Test
  - Partial discharge test (⟨ 5 kV)
- Shield continuity
- Jacket spark test (shielded cable)
- Dimensional measurements

Cable Testing - Qualification

- ICEA, UL, Customer spec
  - Physical Tests - tensile, elongation
  - Aging Tests, degree of cure
  - Insulation Resistance, EM60 (SIC & % pf)
  - Oil Resistance
  - Vertical Flame VW-1 and VTFT
  - Cold Bend
  - Heat Distortion
  - Gravimetric Water Absorption

Cable Selection



Balance of Properties for the intended Application

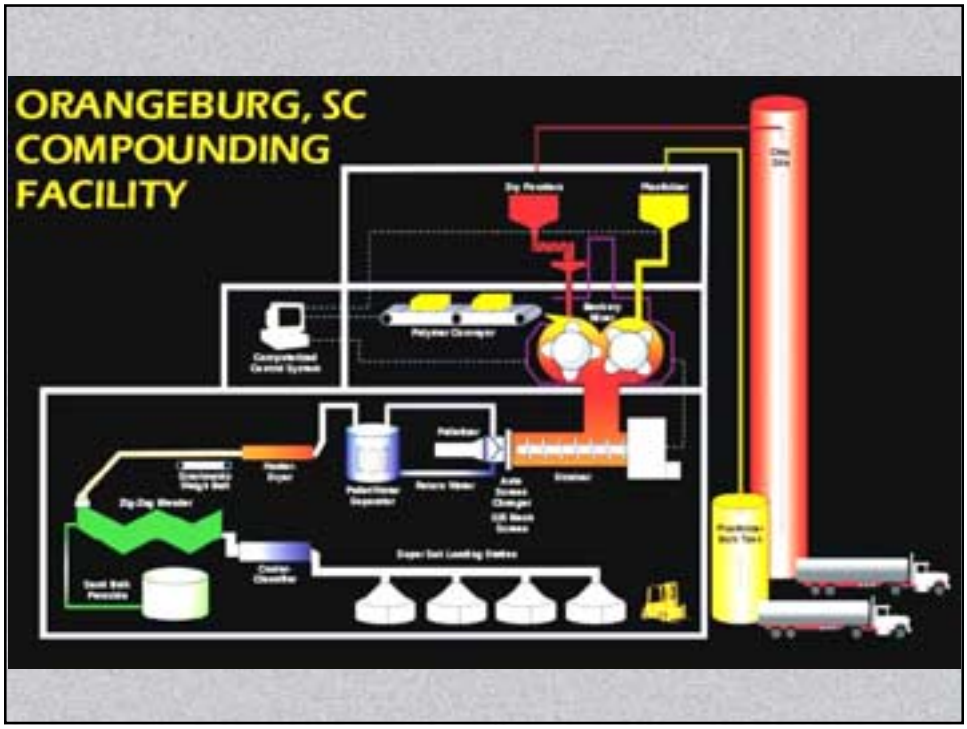
MANUFACTURING PROCESSES

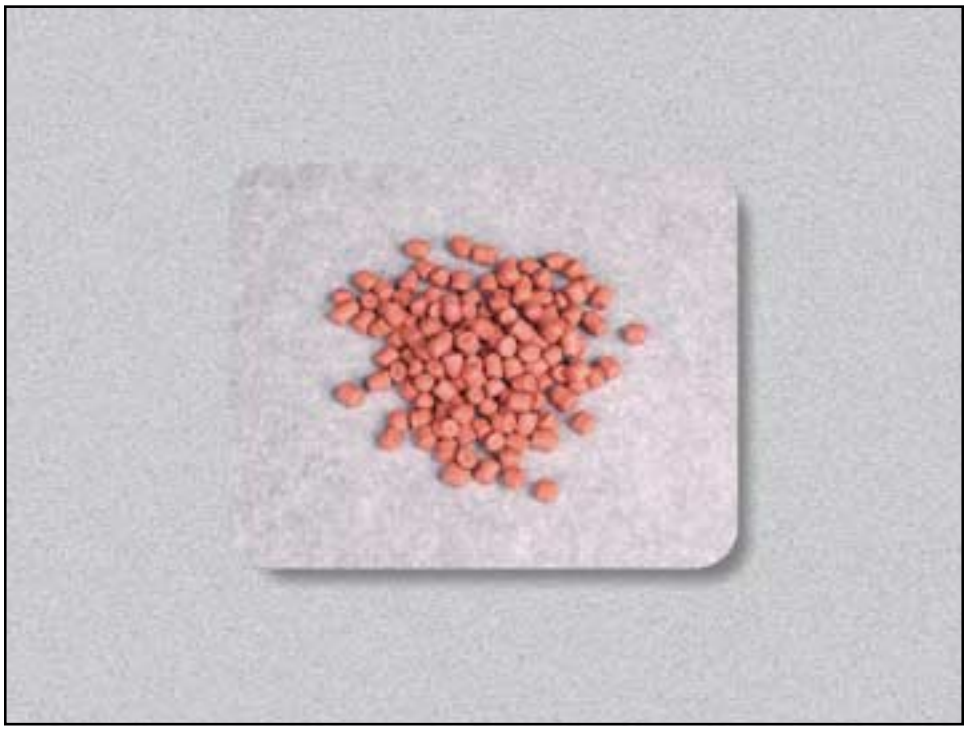
- **COMPOUNDING**
- **EXTRUSION**

FORMULATION

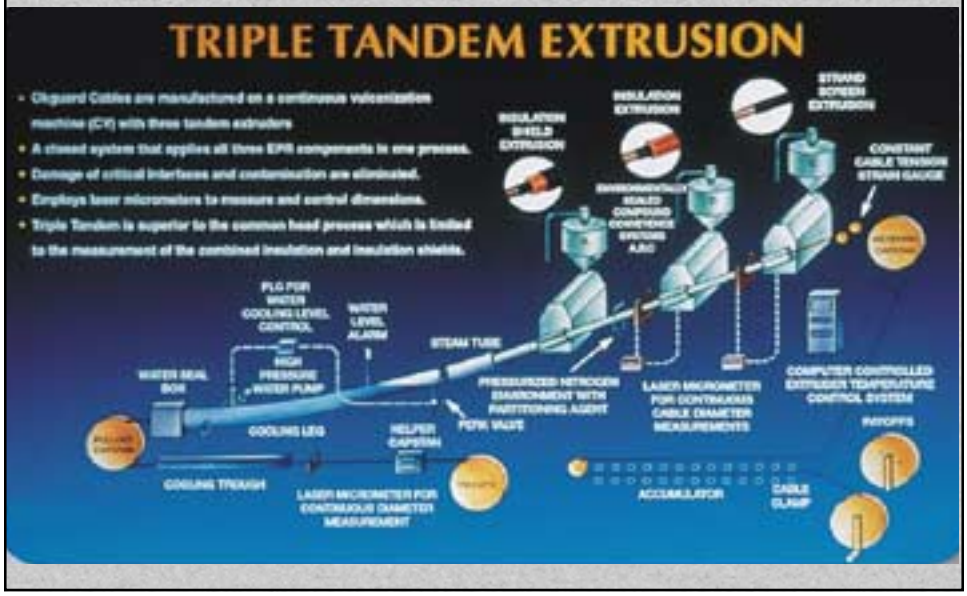
Polymer	dielectric
Clay	filler
Plasticizers	viscosity modifiers
Metal Oxides	heat/moisture stabilizers
Antioxidant	aging characteristics
Co-Agent	co-curing agent
Organic Peroxide	curing agent

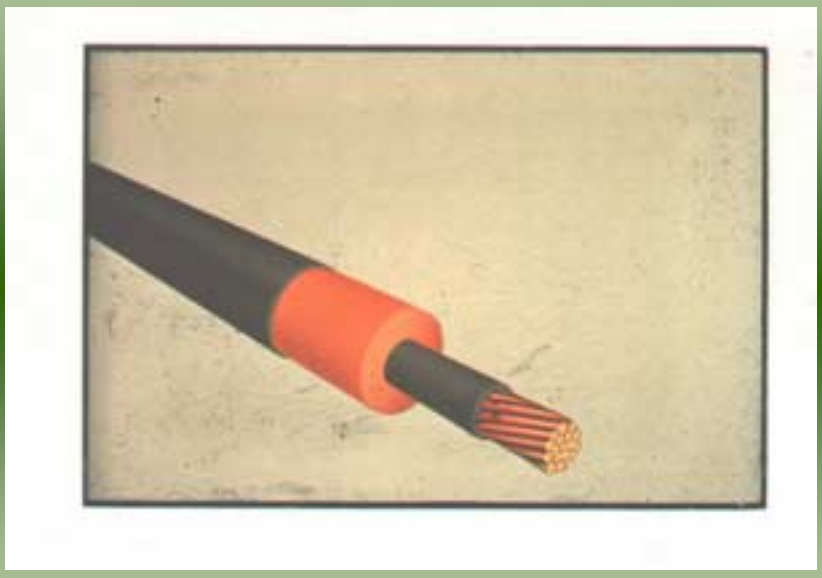
Ingredients

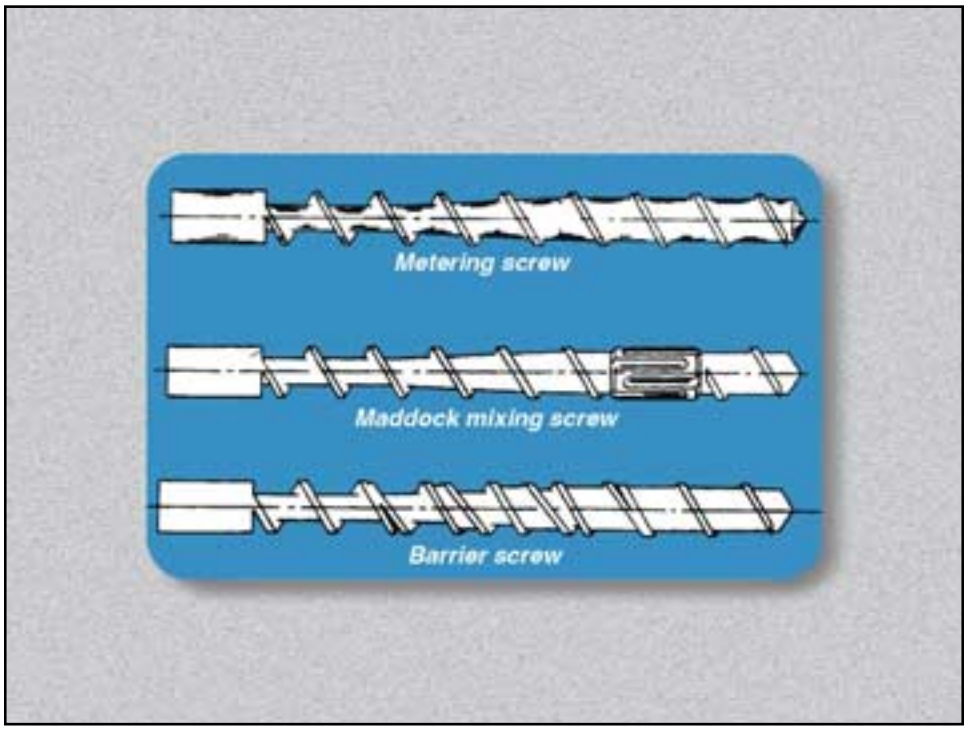

ORANGEBURG, SC
COMPOUNDING
FACILITY

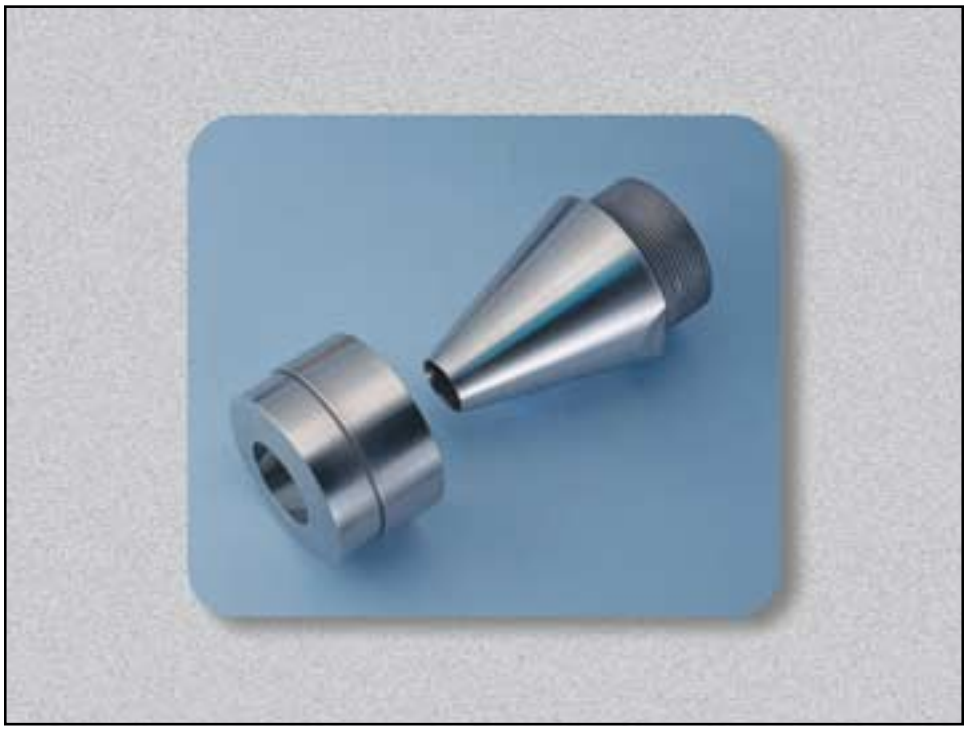


Continuous Vulcanization (CV) Extrusion






Metering screw
Maddock mixing screw
Barrier screw



CABLE INSTALLATION

PARAMETERS

Cable Installation Design Parameters

- Maximum Pulling Tension
- Maximum Sidewall Pressure
- Minimum Bending Radius
- Conduit Fill
- Jamming

Maximum Pulling Tension

Pulling Eyes or Bolts

Triplexed Cables into Duct

$T_m = 0.008 \times n \times cmil$

EXAMPLES

OF

COMPRESSION TYPE

PULLING EYES AND BOLTS

Maximum Pulling Tension

Pulling Eyes or Bolts

Three or Four Cables Paralleled Into Duct

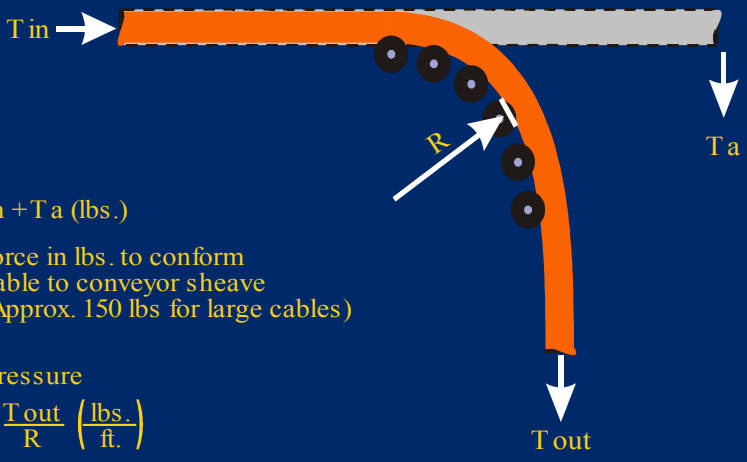
$T_m = 0.008 \times (n-1) \times cmil$

Maximum Pulling Tension

Pulling Grips

1000 lbs per Grip

TENSION AND SIDEWALL PRESSURE IN A BEND



T out = T in + T a (lbs.)

T a = Force in lbs. to conform cable to conveyor sheave (Approx. 150 lbs for large cables)

Sidewall Pressure

$$SWP = \frac{T\,out}{R}\left(\frac{lbs.}{ft.}\right)$$

MAXIMUM SIDEWALL PRESSURE
(lbs. Per ft of radius)

Type of Cable	Conductor Size	
POWER	≤8 AWG	>8 AWG
One Single Cable	300	500
Two or More Cables or Conductors in Cable (parallel or plex)	500	1000
MULTICONDUCTOR CONTROL	ALL SIZES	
One Cable	500	
Two or More Cables	1000	
INSTRUMENTATION	ALL SIZES	
Single Pair	300	
Multipair	500	

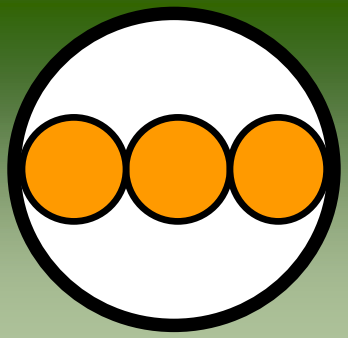
MINIMUM BENDING RADIUS

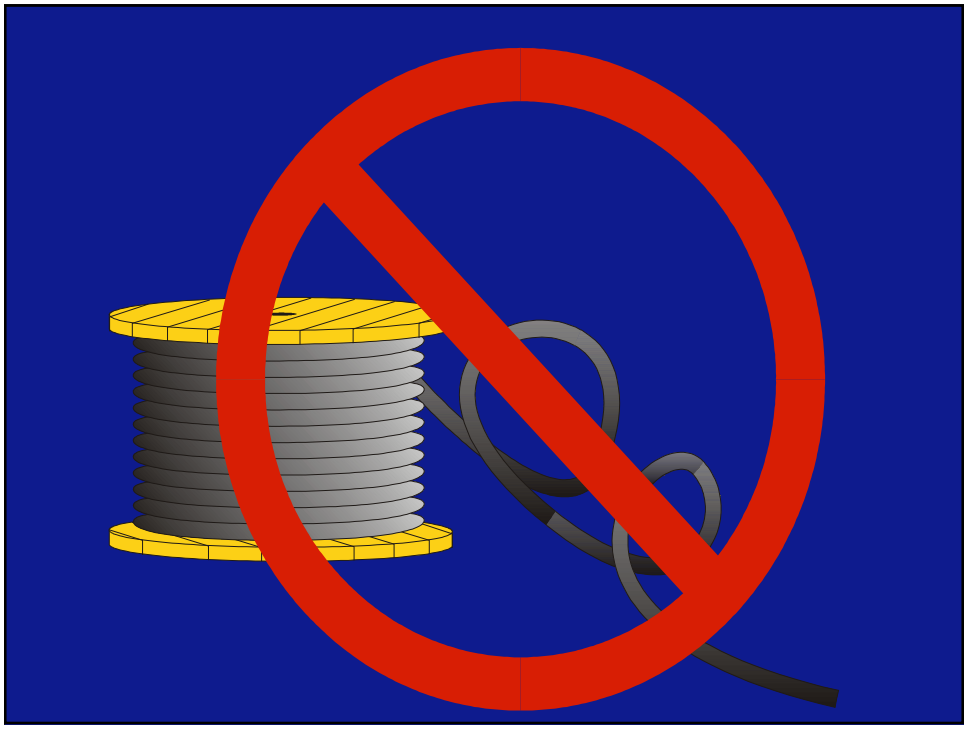
Cables Without Metallic Shielding or Armor

Thickness of Conductor Insulation	Overall Diameter of Cable Inches		
Inch	Minimum Bending Radius as a Multiple of Cable Diameter		
0.155 & less	4	5	6
0.170 - .310	5	6	7
.315 & over	-	7	8

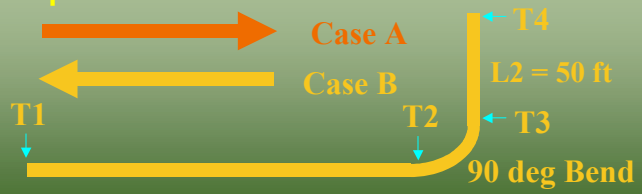
Jamming Conditions

Jamming may occur when the sum of the diameters of the cables being pulled approximately equal the ID of the conduit or duct.





Example



L1 = 500 feet

600 V 1/c 500 kcmil Cu OD = 1.1" Wgt/ft = 1.83#

Maximum Pulling Tension = 0.008 x 500,000cmil = 4000 pounds

Coefficient of Friction = 0.35

Conduit OD = 2”

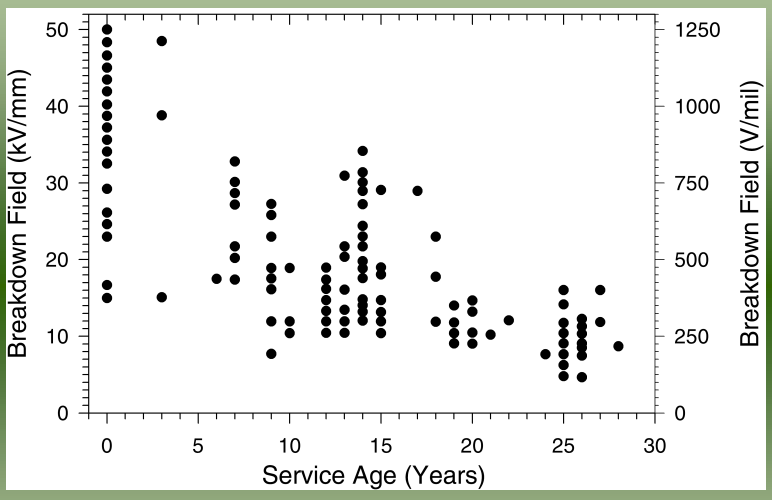
CABLE AGING CRITERIA

VARIOUS POLYETHYLENE INSULATIONS

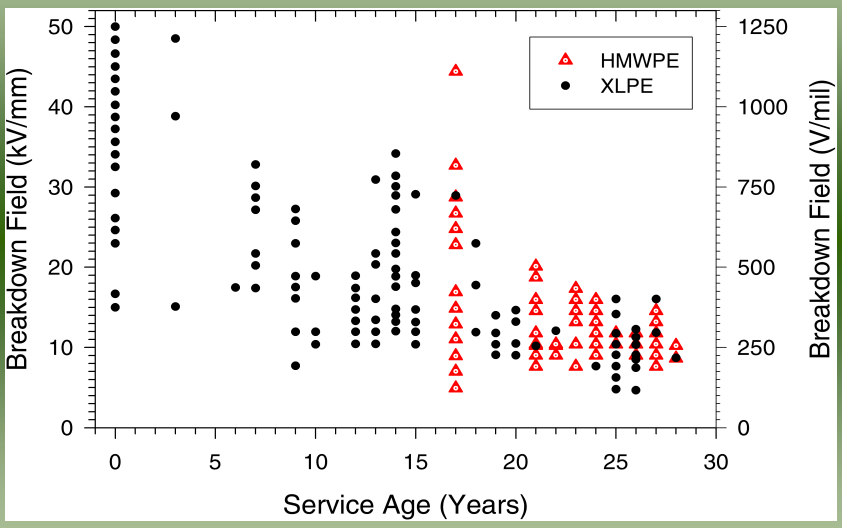
- Bakelite polyethylene 1960
- 4201Bakelite vulcanizable polyethylene 1962
- 4208 (?) 1967
- 6202 TR-HMWPE 1979
- 4202A TR-XLPE 1983
- 7521 TR-HMW-LLDPE 1984
- 4203 NEXT GENERATION TR-XLPE. 1991
- 4300 HIGH VOLTAGE XLPE 1992
- 4202B TR-XLPE 2000
- 8202A EBR 2001
- 8202B 2002

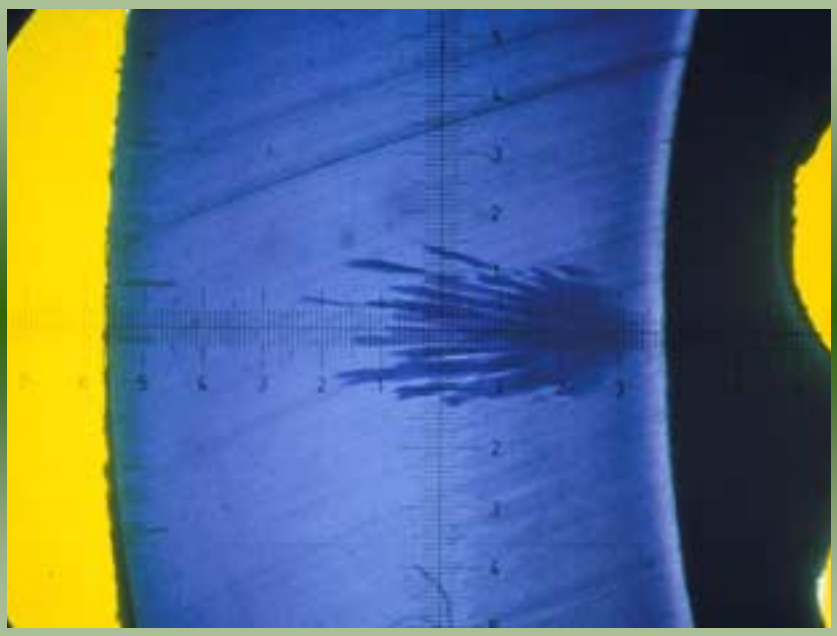
HIGH MOLECULAR WEIGHT POLYETHYLENE (HMWPE)

CROSS LINKED POLYETHYLENE (XLPE)

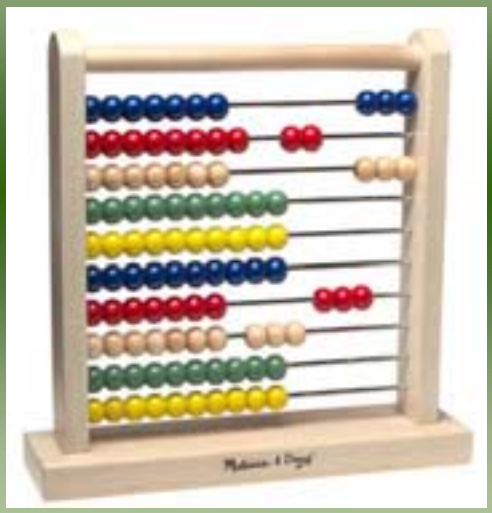


COMPOSITE CHART: HMWPE AND XLPE





ENGINEERING TOOL



ENGINEERING TOOL