Aluminium
Solid and Flexible Cables

“Products for the Next Decade”

Selman ÜNLÜ
Mech. Eng, Deputy GM

Sahra Kablo

Content of Presentation

1- Analyzing the feasibility of Aluminium Cables

- 1.1- Reel Disadvantages of Aluminium Cables
- 1.2- Comparisons of Conductive Metals in various applications

2- Aluminium Cable Applications (_Underground_Aerial_Building_)

3- Aluminium Flexible Cables

- 3.1- Design Criteria&Tests of Aluminium Flexible Cables
- 3.2- Types&Application Areas of Aluminium Flexible Cables
- 3.3- Predictions on Aluminium Flexible Cables

4- Challenges of Aluminium Cables

- 4.1- Integrity of Fine Wires
- 4.2- Connection and Termination

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Ads and DisAds of Aluminium Cables

Advantages of Aluminium Cables

- Cost Saving,
- Historically more stable prices,
- Less sensitive to market fluctuations
- Youngest and most abundant metal
- Lightweight,
- Easy installation,
- Easy maintenance,
- Problem free connection,
- High Corrosion Resistance

Disadvantages of Aluminium Cables

- Larger Radial Sizes, Lack of Space,
- Coefficient of Thermal Expansion,
- Higher Resistivity,
- Mechanical Strength
- Connection Problems,
- Oxidation Layer or Corrosion on Surface
- Bending / Creep Failures

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The Reel Disadvantages of Aluminium Cables

- ***Consumer;*** Doubts about Connection/Termination due to bad reputations in 1960s and 1970s.
- ***Government;*** Not included in Regulation or Standards.
- ***Company;*** easily reach higher turnovers with copper cables during progress payments. So they are reluctant to use Aluminium.
- Cables keep a low percentage cost in many projects, but cars.
- Copper is a very much experienced metal (8000 years) than Aluminium (120years)
- The number of actors in Copper business is higher than Aluminium.

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Characteristics of Conductive Metals

Material	ρ (10^{-8}Ω·m) at 20 °C	σ (10^{7}S/m) at 20 °C
Silver	1.59	6.30
Copper	1.68	5.96
Annealed Copper	1.72	5.80
Gold	2.44	4.10
Aluminium	2.82	3.50
Where **ρ** is the Resistivity; **σ** is the Conductivity.		

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Characteristics of Conductive Metals

Pure Metal or Conductor	Conductivity Percent IACS Volume Basis[1]	Specific Gravity	Conductivity Percent IACS Weight Basis[2]
Pure Metal			
Aluminum	64,90	2,70	213,70
Copper	103,10	8,93	102,60
Gold	84,10	19,32	38,70
Magnesium	38,70	1,74	197,70
Silver	108,40	10,49	91,90
Sodium	41,00	0,97	376,20
Titanium	4,10	4,51	8,10
Electrical Conductors			
AA-1350	61,20	2,705	201.10
AA-8000	61,00	2,71	200.10
Copper	100,00	8,89	100,00

[1] Conductivity on a volume basis compares conductivities of metals for the same cross-sectional area and length.

[2] Conductivity on a weight basis compares conductivities of metals for the same weight.

Referred to as 100% IACS or International Annealed Copper Standard.

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Characteristics of Aluminium and Copper

Conditions	Copper	Aluminium
Equal Cross-Section	**1**	**1**
*Weight	1	0,33
*Resistance	1	1,6
*Conductivity	1	0,625
*Current Carrying Capacity	1	0,8
Equal Conductivity	**1**	**1**
*Cross-Section	1	1,6
*Diameter	1	1,3
*Weight	1	0,49
Equal Thermal Expansion	**1**	**1**
*Cross-Section	1	1,4
*Diameter	1	1,17
*Weight	1	0,42

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Characteristics of Aluminium and Copper

Aluminium Series Used as Electrical Conductor

- 1050, 1070,
- 1120,
- 1350, 1370,
- 5154,
- 6101, 6201,
- 8030, 8070, 8176

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Characteristics of Aluminium and Copper

Property	Copper (Cu-ETP)	Aluminium (1350)	Units
Electrical conductivity (annealed)	101	61	%IACS
Electrical resistivity (annealed)	1.72	2.83	uΩcm
Thermal conductivity at 20˚C	397	230	W/mK
Coefficient of thermal expansion	17×10^{-6}	23×10^{-6}	/˚C
Tensile strength (annealed)	200-250	50-60	N/mm^2
Tensile strength (half-hard)	260-300	85-100	N/mm^2
Elastic modulus	116-130	70	N/mm^2
Thermal Storage Capacity	0.092	0.214	Cal/gr.^oC
Fatigue Strength (annealed)	62	35	N/mm^2
Fatigue Strength (half-hard)	117	50	N/mm^2
Specific heat	385	900	J/kgK
Density	8.91	2.70	g/cm^3
Melting Point	1083	660	˚C

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Comparison of Aluminium and Copper in Cable

Electrical Equivalence

"Transferring Power form one source to consumer" described as

Equal Distance	Equal Resistance	Equal Voltage Drop
$L_{Al} = L_{Cu}$	$R_{Al} = R_{Cu}$	$DU_{Al} = DU_{Cu}$

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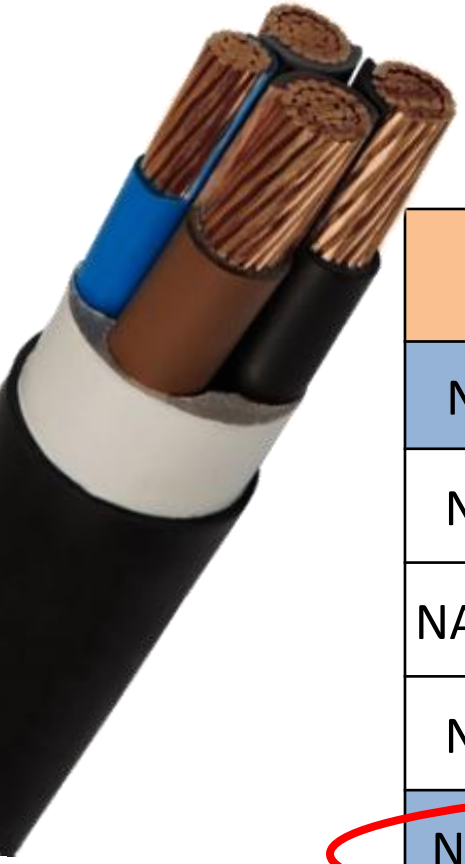
Comparison of Aluminium and Copper in Cable



What if…

Type	Cross-Section	Price (USD/km)	Diameter (mm)	Weight (kg/km)
NYY RM	4x95	19,53	42,5	4975
NAYY SE	4x120	4,18	41	2500
NA2X2Y SE	4x120	4,15	41	2260
NAYY SE	4x150	5,13	45	2770
NAY2Y SE	4x150	5,08	45	2550
NA2X2Y SE	4x150	5,15	45	2450

LME_{Cu}	4.750 USD/ton
LME_{Al}	1.650 usd/ton

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Comparison of Aluminium and Copper in Cable

Copper Cable			Equivalent Aluminium Cable			Cu/Al Ratio	% Price Match
Cable Type	Cross-Section	Price (USD/km)	Cable Type	Cross-Section	Price (USD/km)		
NYY	4X10	2357	NAYY	4X16	782	3,01	66,82
NYY	3X16+10	2572	NAYY	3X25+16	1229	2,09	52,22
NYY	3X25+16	5091	NAYY	3X35+16	1456	3,50	71,40
NYY	3X35+16	6639	NAYY	3X50+25	2016	3,29	69,63
NYY	3X50+25	9513	NAYY	3X70+35	2680	3,55	71,83
NYY	3X70+35	13208	NAYY	3X120+70	4419	2,99	66,54
NYY	3X95+50	17979	NAYY	3X150+70	5239	3,43	70,86
NYY	3X120+70	22970	NAYY	3X185+95	6489	3,54	71,75
NYY	3X150+70	27727	NAYY	3X240+120	8454	3,28	69,51

Cu_{LME}	4.750 USD/ton
Al_{LME}	1.650 usd/ton

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Comparison of Aluminium and Copper in Cable

Copper Cable				Equivalent Aluminium Cable			
Cable Type	Cross-Section	Cu Factor	Price (USD/km)	Cable Type	Cross-Section	Al Factor	Price (USD/km)
NYY	4x10	356	2282	NAYY	4x16	173	796
NYY	4x95	3382	19529	NAYY	4x150	1620	5967
NYY	4x240	8544	49653	NAYY	4x400	4320	15200
NYM	4x2,5	89	584	NAYM	4x4	43	505
NYM	4x6	213,6	1317	NAYM	4x10	108	630
H07V-K	1,5	13,35	76,15	AH07V-K	2,5	6,75	52
H07V-K	70	623	3404	AH07V-K	120	324	1680
H07V-K	150	1335	7363	AH07V-K	240	648	3420
H05VV-F	4x0,75	26,7	216	AH05VV-F	4x1,5	16	175
H05VV-F	4x2,5	89	586	AH05VV-F	4x4	43,2	425

Cu_{LME}	4.750 USD/ton
Al_{LME}	1.650 usd/ton

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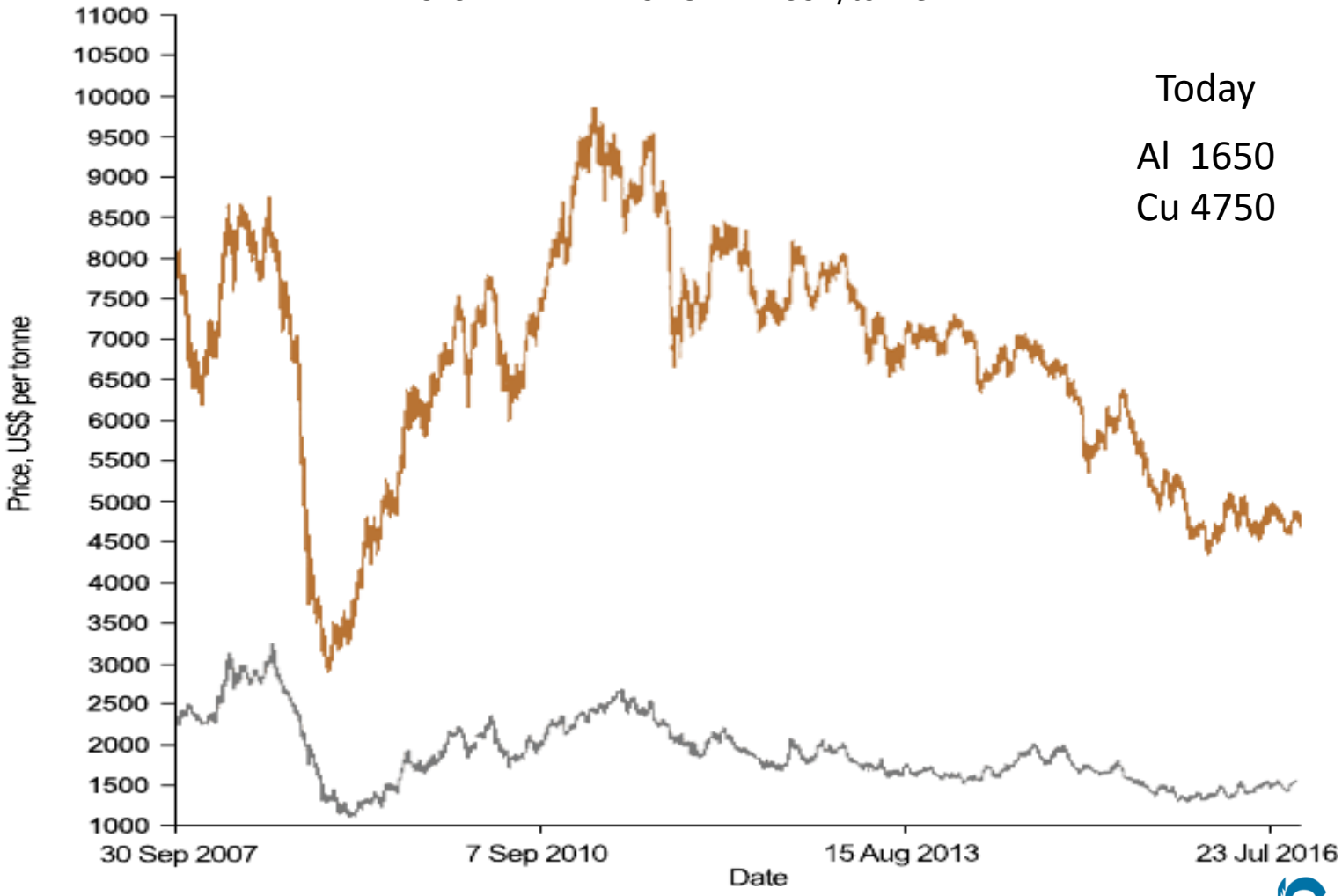
Comparison of Aluminium and Copper in Cable

LME CASH METAL PRICE GRAPH USD/tonne



Today

Al 1650

Cu 4750

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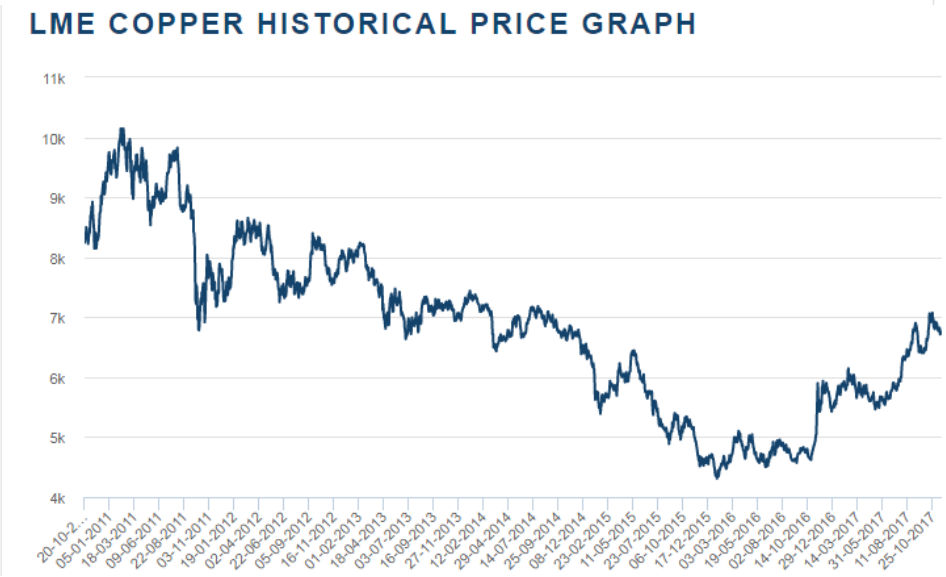
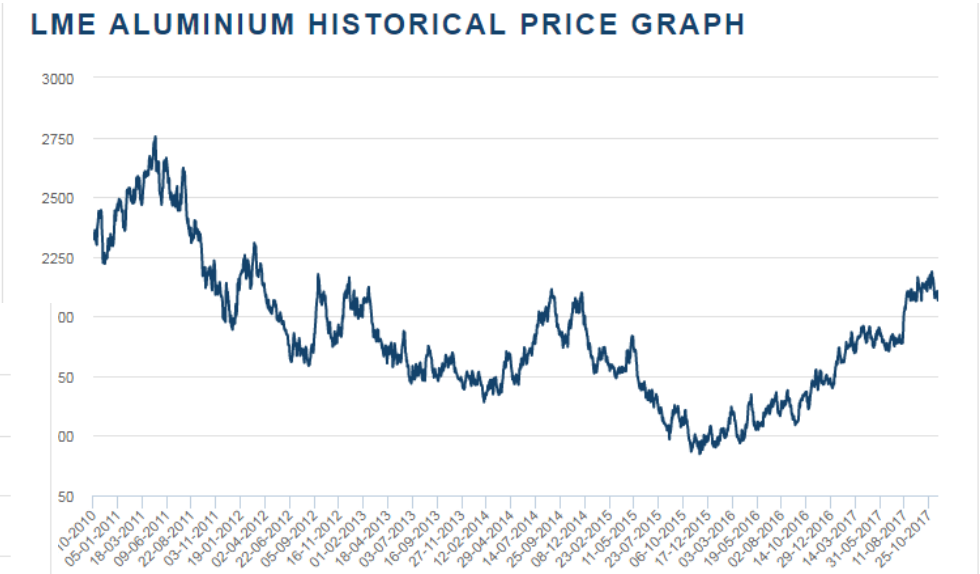
Comparison of Aluminium and Copper in Cable

LME CASH METAL PRICE GRAPH USD/tonne

LME_{Al} 2067 USD/Mton

LME_{Cu} 6750 USD/Mton





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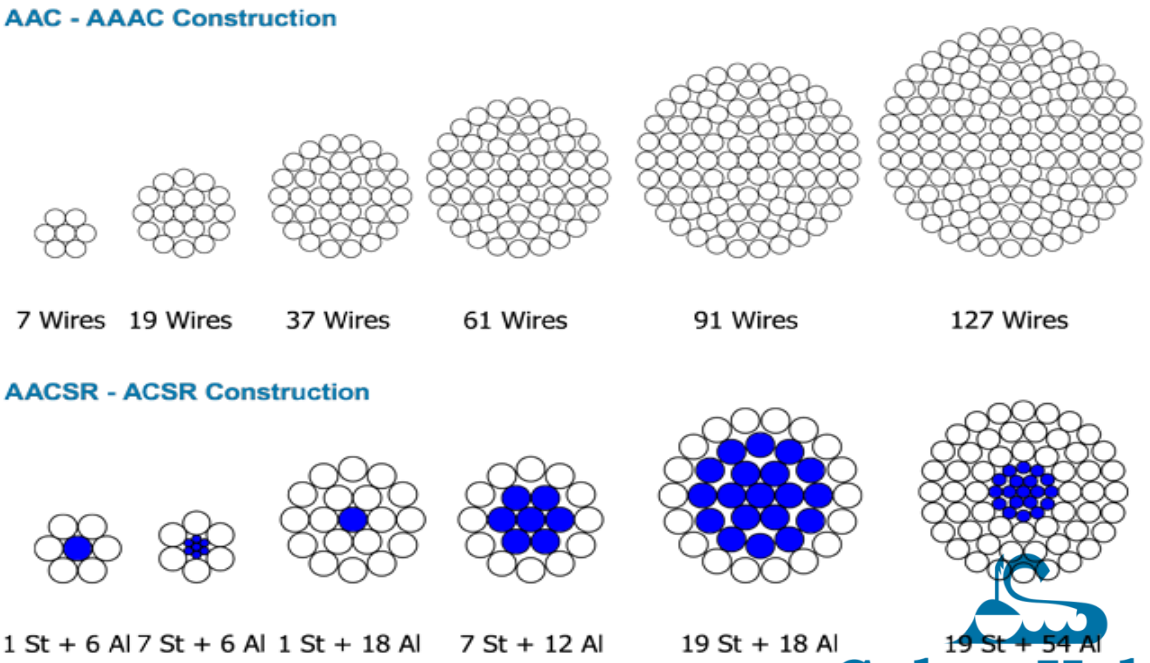
Overhead Conductors

- AAC
- ACSR
- AAAC
- AACSR



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Aerial Bundled Cables

- For temporary supplies,
- In theft prone areas instead of bare conductors,
- In hilly terrains,
- In developing urban complex,
- Danger risk of touching trees,
- In rainy lands,

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Types of LV&MV Aerial Bundled Cables

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Types of LV&MV Aerial Bundled Cables

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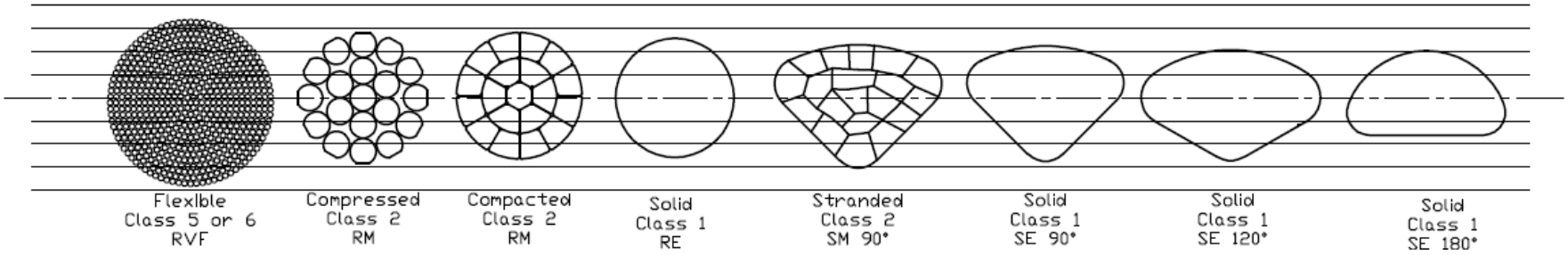
Underground Cables

- Conductor Types



- Insulation&Sheathing;

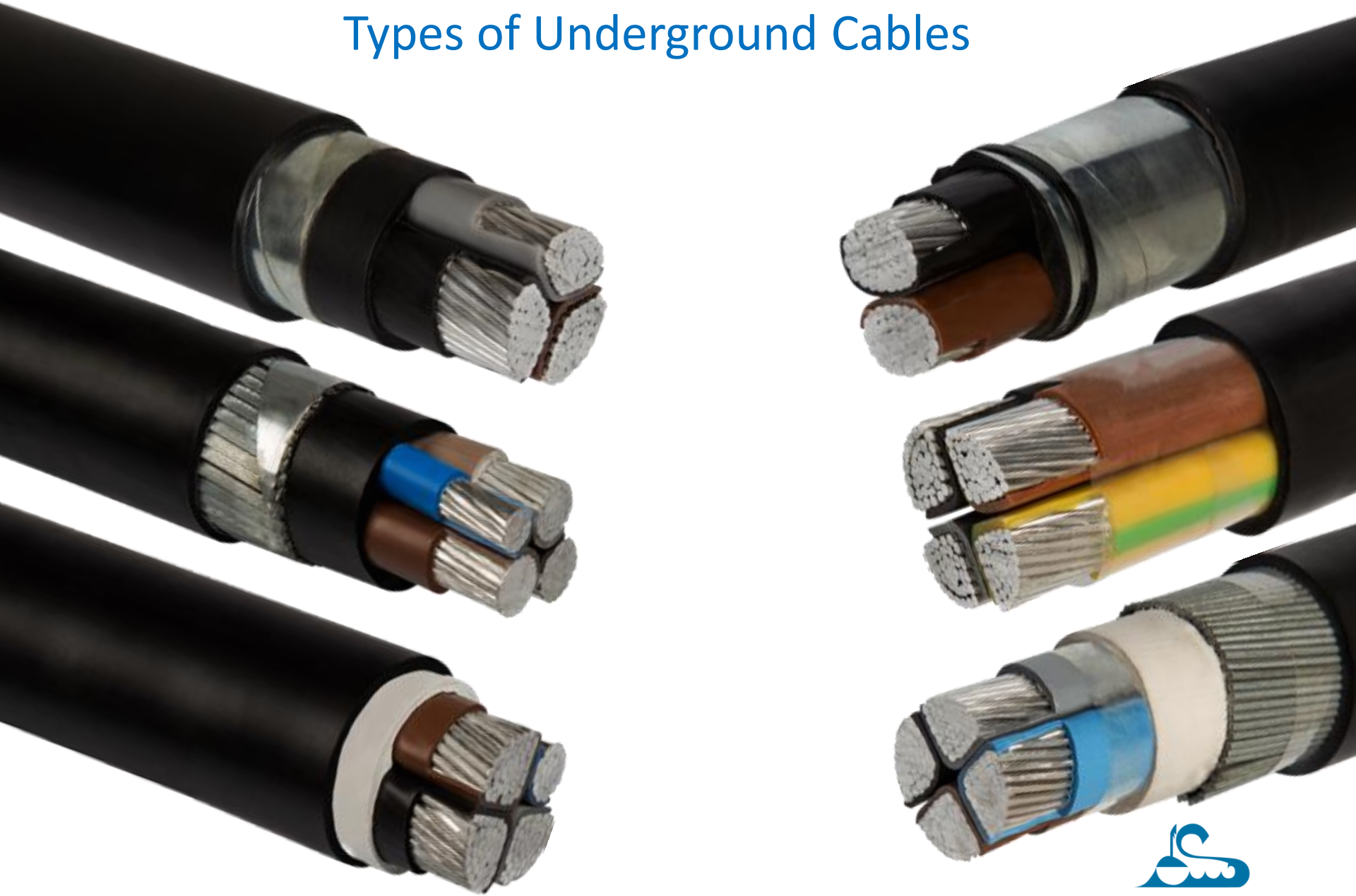
XLPE, PVC, HFFR, Rubber..

- Armouring

SWA, STA, AWA, Cu, CW

- Many varieties can be applicable

Types of Underground Cables



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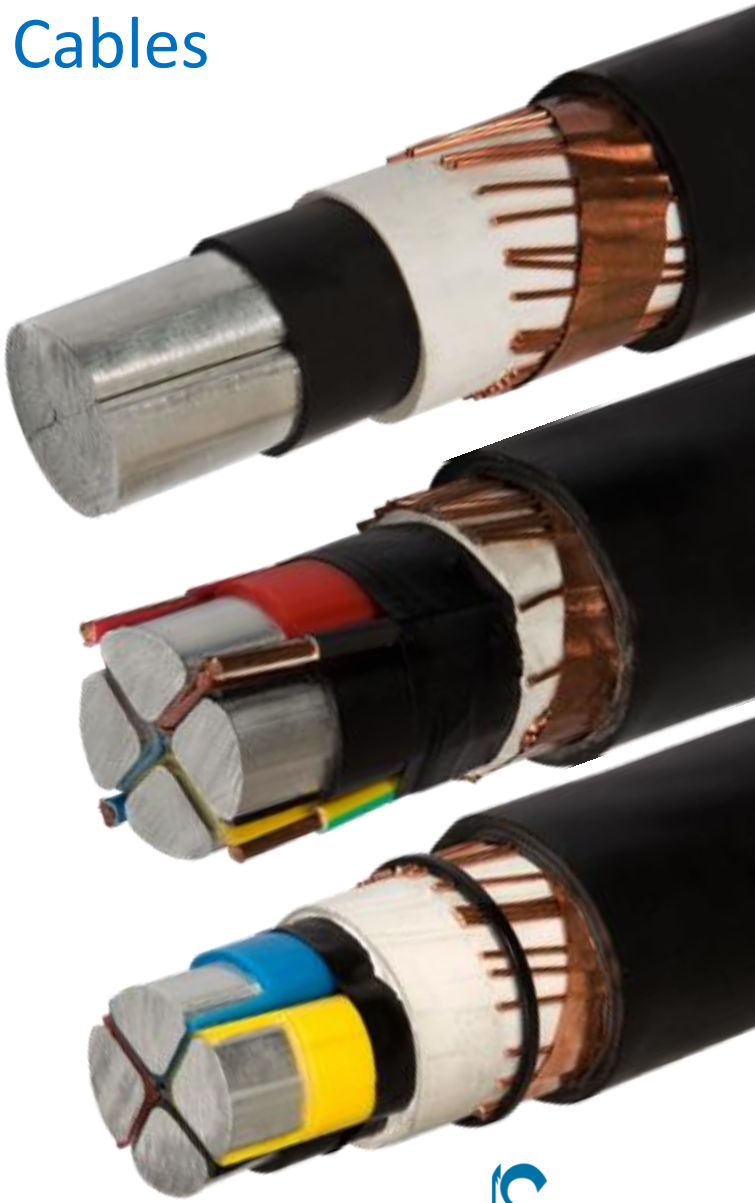
Types of Underground Cables



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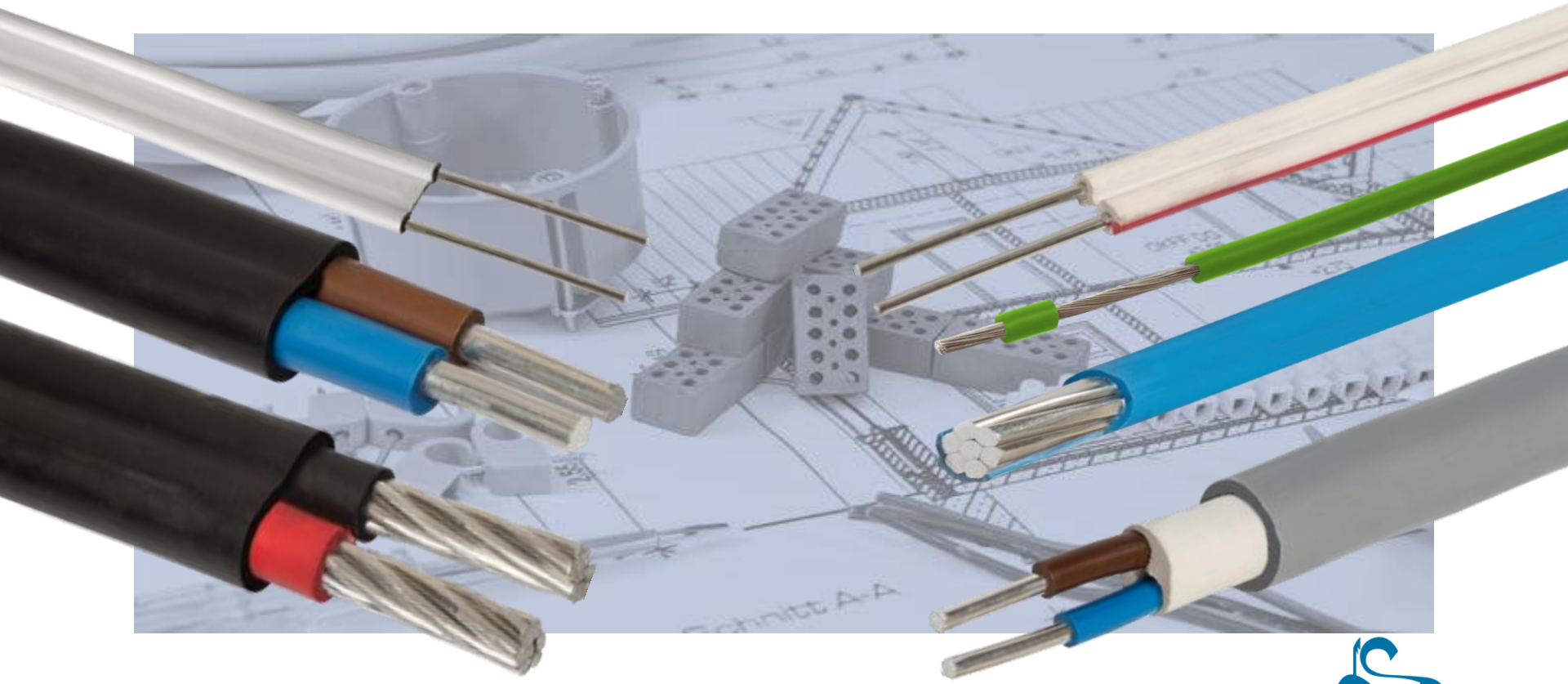
Aluminium Building Cables

“Today, Aluminum building wiring is safe and reliable”

Since 1970s, with the development of improved Conductors and connectors, changes have made installing aluminum building wire as simple as installing copper.



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Aluminium Building Cables

During Connection, Please Consider

1. Interoperability of Accessories and Aluminium,

2. Workmanship Quality,

3. Physical Properties of Accessories,

4. Thermal Expansion Differences,

5. Creep and Voltage Drop Conditions,

6. A Thin protective Oxide layer on Aluminium is broken during termination,

7. Material Grade of Conductor,

8. Proper tightening (torquing) is essential to achieve a reliable connection,

9. All electrical connections should be periodically inspected,

10. A compatible Oxide Inhibitor is recommended,

11. Environmental Conditions,

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Aluminium Building Cables

During Connection, Please Avoid from

1. Poor Workmanship,

2. Undesirable Accessories,

3. Imprudent Termination,

4. Improper Tightening Torque,

5. Rapid conductor deformation due to creep,

6. Excessive mechanical load and connector degradation,

7. Do not re-torque the terminations as part of routine maintenance, if not loose,

8. Over tightening can lead to damaged conductors and connection points

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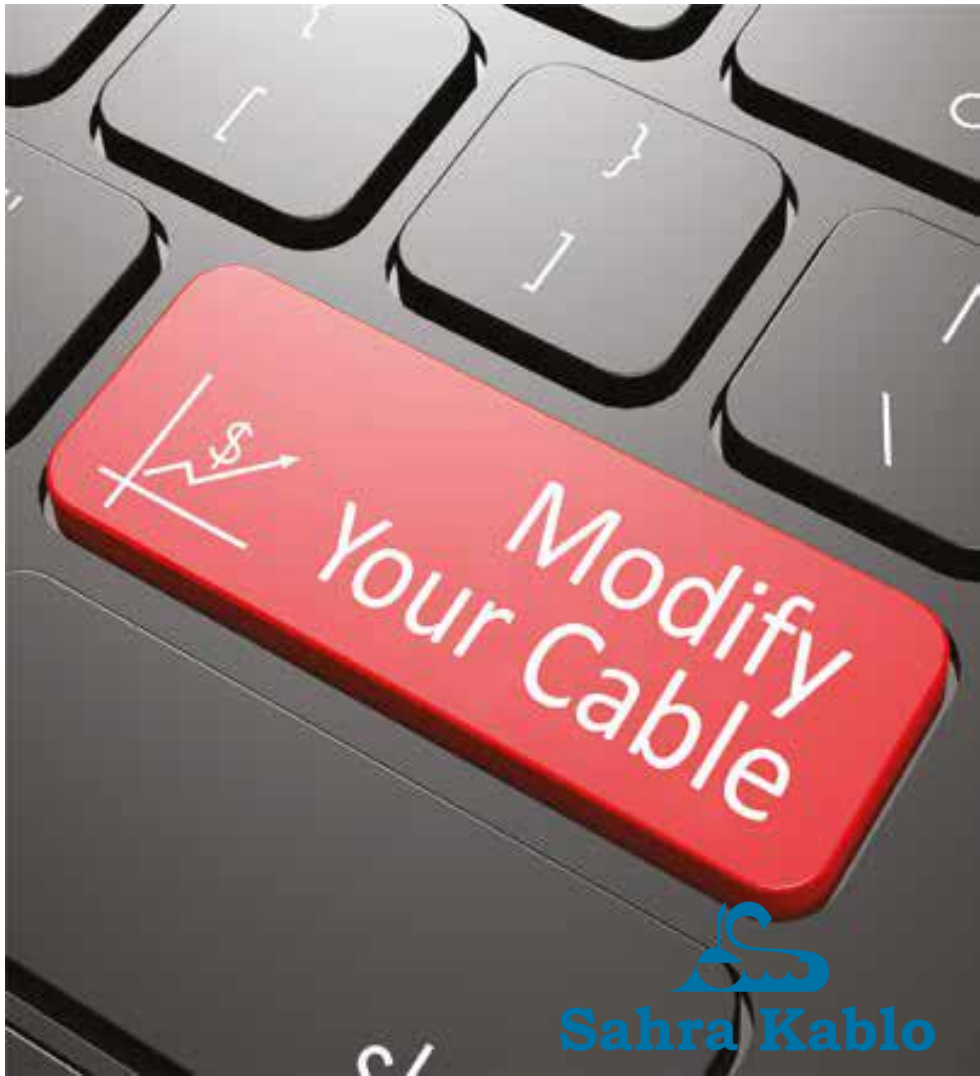
Aluminium Flexible Cables

“Product for the Next Decade”

Aluminium Flexible Cable is designed for

- Wind Turbine Generators
- Heat and Power Plants
- Railway Vehicles
- Aircrafts, Vehicles, Automobiles
- Transformer Stations
- Switching Stations / Control Panels
- Photovoltaic / Solar Systems
- Fixed&Flexible Installation
- Surface Mounted Installation
- Concealed Installation



Aluminium Flexible Cables

Design Criteria for Flexible Cable

- ***Standards&Specifications***

  ISO 6722
  LV 112-2
  JASO D 603 / 611-94
  ASTM B470
  EN 60228 Class 5 Copper Equivalent
  Manufacturer Datasheets

- ***Motion Types***

  Torsional
  Bending
  Rolling
  Fixed or Flexible

- ***Installation Conditions***

  Oil/Grease/U.V/Ozone Resistance,
  Flame/Fire/Smooke Performance
  Operating Temperature Range

Limitations for AFC

?__Temperature Limits

?__ Motion Limits

?__ Vehicle Location Limits

?__ Wire Size Limits

?__ Vibrations

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Aluminium Flexible Cables

Motion Types

Our target is

"Strain-Relief Conductor and Tension-Proof Insulation"

- The Higher Tensile Strength,
- The Finer Wires,

} The Higher Flex Life,

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Aluminium Flexible Cables

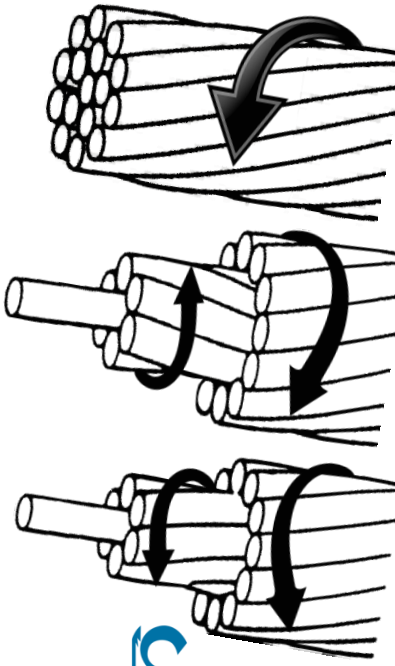
Motion Types

Flexible Conductor Stranding Types

BUNCH: Same Lay ratio and direction, mostly used in fixed installations. Toron/Stranding bunching of Rope Lay or Cross-Sections up to 10mm^2

CONCENTRIC CONTRA-HELICAL: Each layer has a reversed lay direction and an increasing or same lay length in each succeeding layer. Applicable for torsional and flexible motions.

ROPE LAY or CONCENTRIC UNILAY: Individual bundles of toron/stranding twisted together into groups with the same lay direction and length (or inreasing lay length) with a well defined geometric configuration. Applicable for torsional and flexible motions.



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Aluminium Flexible Cables

Motion Types

Flexible Conductor Stranding Parameters

1- Tensile Strength of Wires

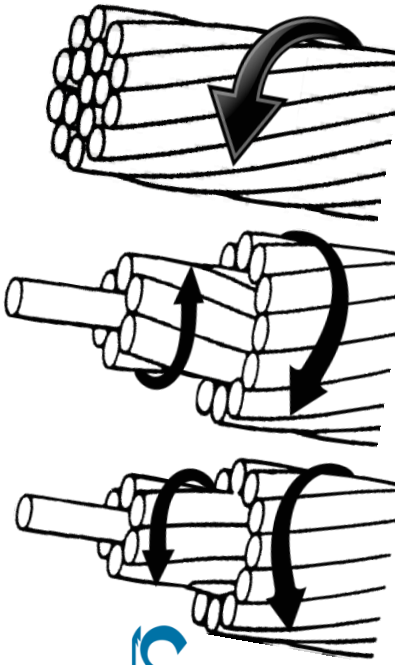
2- Wire Diameters

3- Number of strands

4- Lay directions of strands and layers

5- Lay Lengths of strands and layers

6- Annealing or Heat Treatment



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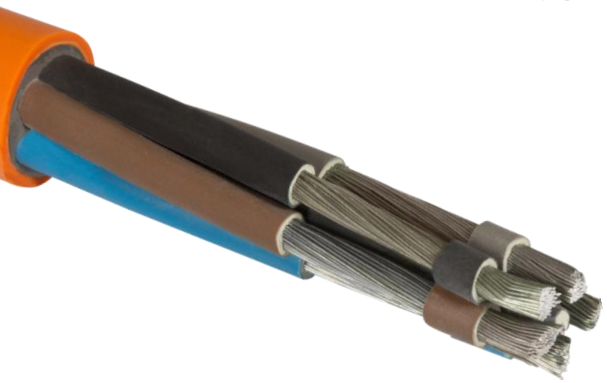
Aluminium Flexible Cables

Extension Leads_Multi Core Cables



Cable Construction- PVC

- Flexible Aluminium Conductor
- Annealing of Wires (Optional)
- Colourful Separator Film/Tape
- PVC Insulation
- PVC Sheath

Cable Construction- CSP

- Flexible Aluminium Conductor
- Annealing of Wires (Optional)
- Colourful Separator Film/Tape
- CSP Insulation
- CSP Sheath

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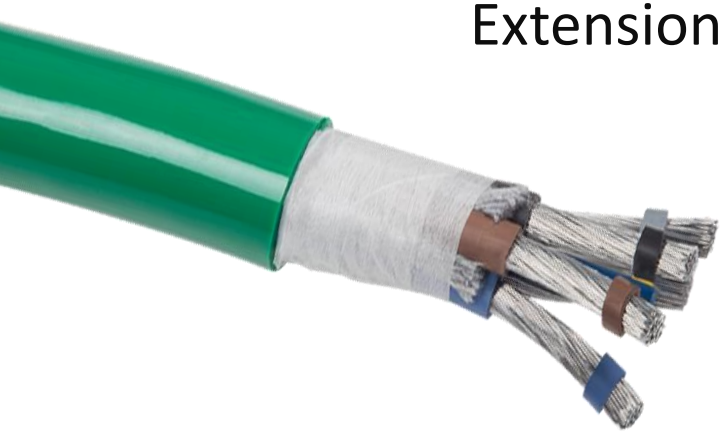
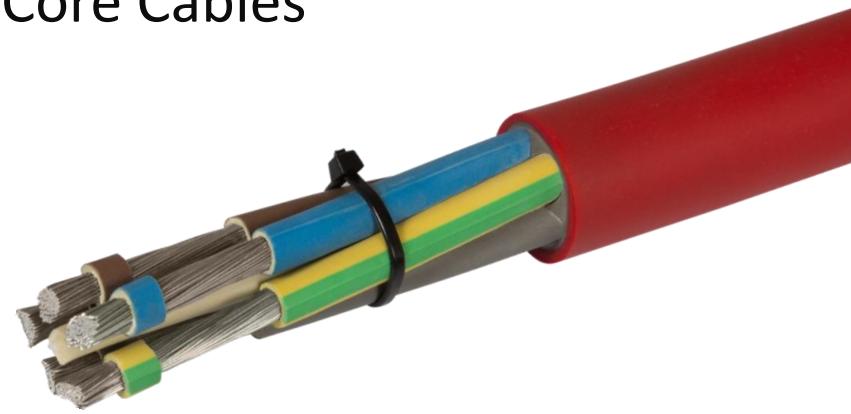
Aluminium Flexible Cables

Extension Leads_Multi Core Cables



H07BQ-AF / S07BQ-AF

- Flexible Aluminium Conductor
- Annealing of Wires (Optional)
- XLPE Insulation
- Filler Cotton Yarn
-PUR Sheath



H07BN4-AF / 07BN4-AF

- Flexible Aluminium Conductor
- Annealing of Wires (Optional)
- Colourful Separator Film/Tape
- EI 7 EPR Insulation
- EM 7 or CSP Sheath

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Aluminium Flexible Cables

Wind Turbine Cables

Cable Construction

- Flexible Aluminium Conductor
- Annealing of Wires (Optional)
- Transparent Separator Film/Tape
- EPDM Insulation
- Galvanized Steel Wire Shielding
- CSP Sheath

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Aluminium Flexible Cables

Multi Core Cables

Cable Construction

- Flexible Aluminium Conductor
- Transparent Separator Tape
- Thermoplastic Elastomeric Insulation
- Thermoplastic Elastomeric Sheath

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Aluminium Flexible Cables

Railway Cables

H07BQ-AF / S07BQ-AF

- Flexible Aluminium Conductor
- Annealing of Wires (Optional)
- Colourful Separator Film/Tape
- EI 6 EPR Insulation
- TPE-U PUR Sheath

Railway – CSP Sheathed

- Flexible Aluminium Conductor
- Transparent Separator Tape
- CSP Sheath

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Aluminium Flexible Cables

One Core Flexible Cables

Welding Cables

- Flexible Aluminium Conductor
- Annealing of Wires (Optional)
- Colourful Separator Film/Tape
- EM 5 Sheath

Railway – PVC Sheathed

- Fine Aluminium Wires
- Compressed Rope Lay Stranding
- PVC Sheath

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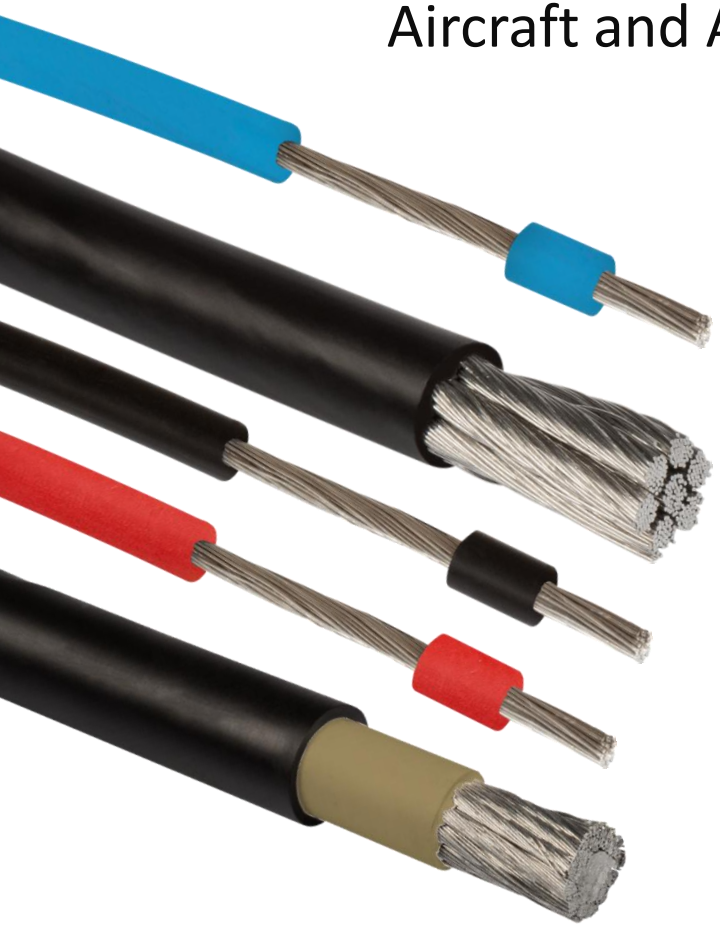
Aluminium Flexible Cables

Aircraft and Automotive Power&Battery Cables



Characteristics

- Applicable in Vehicles, Aircrafts since 2000s
- Ref. Standard: LV 112-2 and ISO 6722-2
- Fine Annealed Aluminium Wires
- PVC, XLPO, HFFR or other insulation materials
- Applied to battery, door, roof compartments
- Cross-Section Range 0,75≈160 mm^2
- Weight: Approx. 60% of Harness consists of Cables.
- Carbon Emission: Approx. every 100 kg reduction saves 0,6 lt in 100 km.

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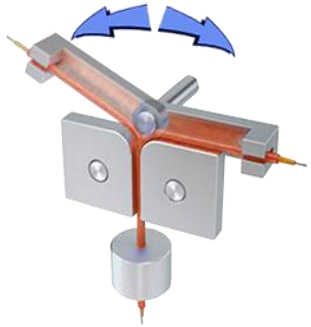
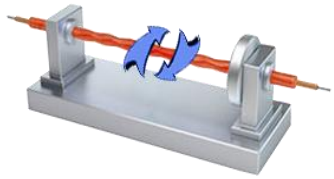
Aluminium Flexible Cables

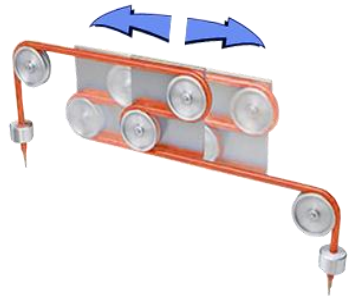
Tests of Aluminium Flexible Conductor&Cable

Flex Life Tests acc. to ASTM B 470, UL 1277 or OEM Specifications

- Rolling Tests,
- Bending Tests,
- Torsional Tests,







Aluminium Series

- DIN EN 573-3

Individual Wire Tests

- ISO 6722-1, ISO 6722-2
- ASTM B 470, ASTM B230, ASTM B233, ASTM B609, BS 2627

Insulation&Fire Tests

- OEM Specifications, ISO 6722-1 or Equivalent Copper Standards

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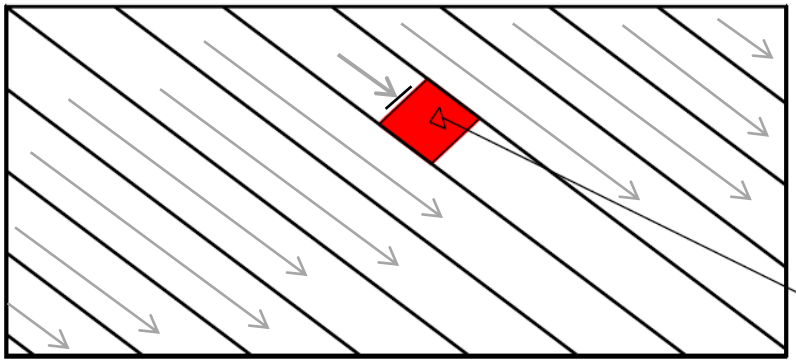
Integritiy of Fine Wires



In case of Wire Cut/Breakage, Current can jump to next Copper wire, but Aluminium.

?

1. Correct Stranding Design to defined Motion Type

2. Correct Alloy Composition to Correct Cross-Section

Design

---

1. Reduced Friction in Stranding/Bunching Process

2. Sensitive Wire Break Sensors

3. Annealing or Heat Treatment of Fine Wires to minimize backtwists

4. Colourful Separator Tape on Conductor

Production

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Connection, Termination, Crimping

Confusions about Aluminium Connection

- ***Oxidation***

- Corrosion (Electromechanical_Galvanic)

- Creep (Cold Flow) & Thermal Expansion

- Fatigue Performance in Mechanical Vibrations&Electrical Load Cycles

- ***Workmanship***

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Connection, Termination, Crimping

Workmanship

- ***Operator*** is the most important "***system component***"

- He must be competent and craftsman.

- ***The process is not just*** "insert wire, compress lug".

- Poor Workmanship&Imprudent Termination is generally recognized as the primary source of failed connections.

- You can ***take precautions*** against oxidation but ***not workmanship.***

- An faulty operation might even cause a fire.

"Follow the guidelines!!!"

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Connection, Termination, Crimping

Oxidation

- Very fast a thin layer of Aluminum Oxide (Al_2O_3 forms) on the surface. Al_2O_3 is one of the ***hardest*** and ***brittle*** materials known and acts as an electrical insulator.

- This layer can reach 4nm thickness (increasing with time)

- Resistivity 10^12 Ω m

- Dielectric Strength 35 MV/m

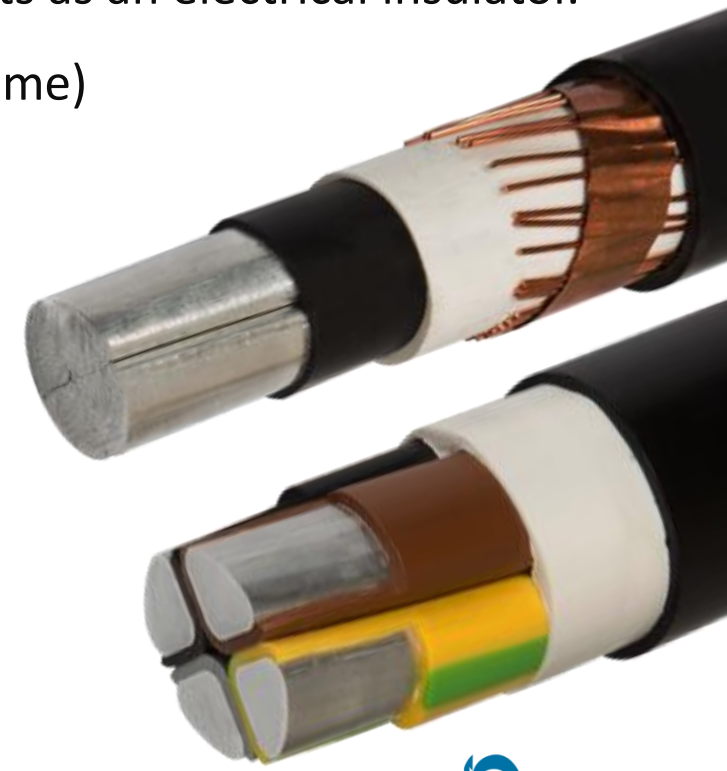
- Theoretical Surface Resistance ≈ 4 kΩm^2

- Breakdown Voltage for contacts ≈ 0,14 V

- **?**_Power Application (>100 Volt):

- **??**_Automobile Application (=10 Volt):

- **???**_Communication&Signal (<1 Volt):



Source: Prof. Dr.-Ing. Hans-Dieter Ließ
Bundeswehr University Munich

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Corrosion

inherent tendency to revert from a processed, metallic state to their natural state, "***Ore***".

Aluminium

Bauxite Ore
Aluminium Hydroxide
($Al(OH)_3$)

Alumina
Aluminium Oxide
(Al_2O_3)

Aluminium

Corrosion (Galvanic_Electrochemical)
Contact with Salt Water or Moisture → **Bauxite Ore**

Oxidation
Contact with Oxygen or Air → **Alumina**

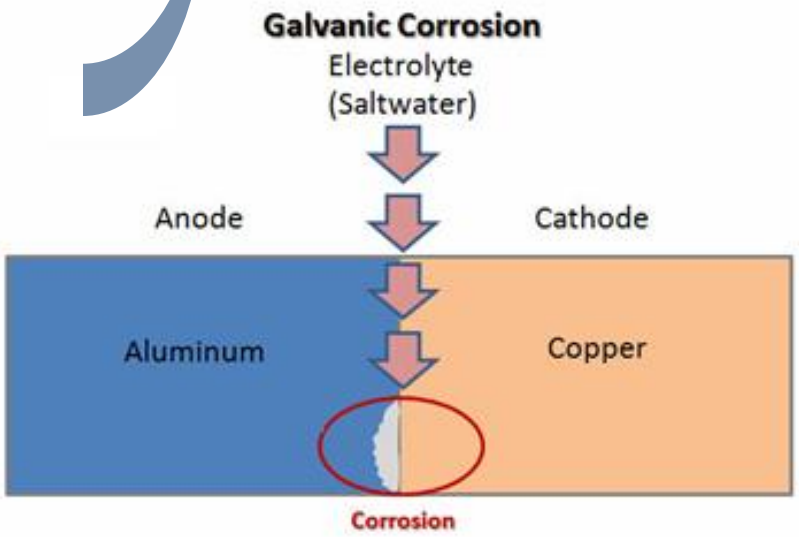

Photo: Klauke

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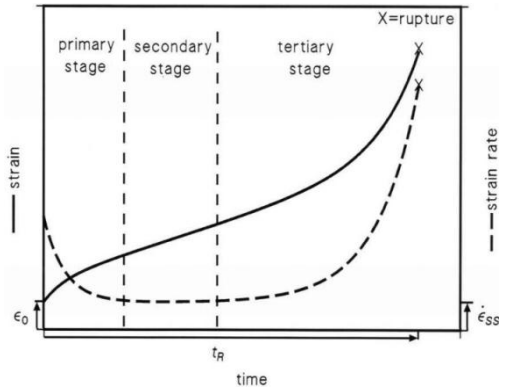
Creep&Cold Flow&Thermal Expansion

Assumption	Cross-Section	
	Cu	Al
Equal Conductivity	1,00	1,60
Equal Thermal Expansion	1,00	1,40

$$\varepsilon = \varepsilon_0 + \varepsilon(\sigma, T, t)$$



To prevent Creep&Cold Flow in the Conductor

✓ Correct Alloy Composition - Motion Type Matchup (i.e 6mm^2)

✓ ***Correct Compression Lug***

✓ ***Compression Force; partial cold weld is preferred.***

✓ ***Qualified Workmanship***

✓ Correct Conductor Stranding - Motion Type Matchup

✓ Consider Installation Factors

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Fatigue Performance

In fixed installation of Solid and Stranded Conductors;

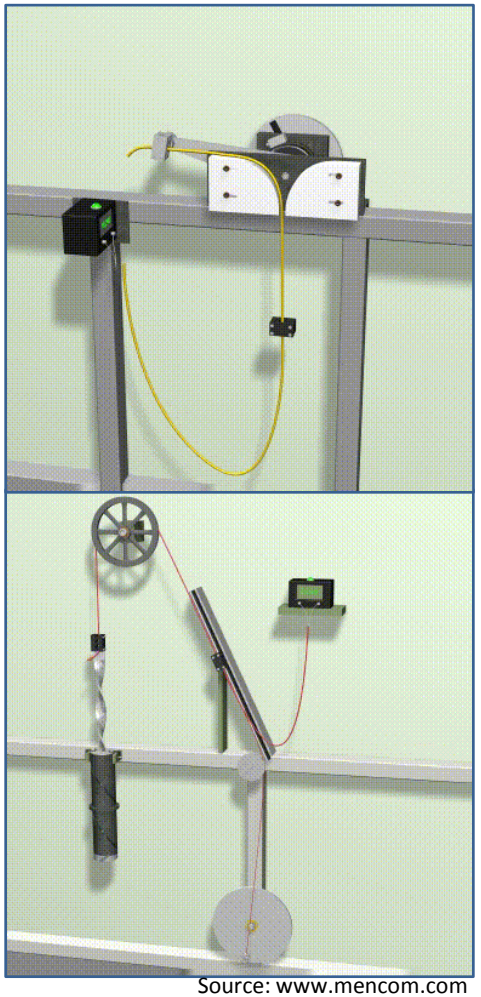
- ✓ Correct Conductor - Connector Matchup (RE ,SE ,RM, SM)
- ✓ Correct Cross Section - Lug Selection
- ✓ Qualified Workmanship
- ✓ Heat shrinkable Sleeve on both insulation and connector lug
- ✓ Consider Environmental Conditions (-40^{0}C…+40^{0}C, Heavy Duty)

In fixed installation of Flexible Cable;

If you make a good connection, no problem for small Mechanical Vibrations and Electrical Load Cycles, i.e Automobiles.

In flexible installation of Flexible Cable;

Neither market nor industry has enough knowledge, demand and experiences about the fatigue behaviors.



Source: www.mencom.com

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How should be a qualified Compression Lug?

- ***Compound*** additive with ***grinding effect*** breaks oxide layer and also prevents further oxygen penetrating the contact joints.

- Barrier Design (must be sealed with a plastic plug provides a good water and oil blockage)

- ***Maximum Contact Surface*** (Hexagonal Crimping or F Crimping)

- Longer Lug contributes connection quality

- Tin plating stops the lug from oxidizing, also useful for galvanic activity.

- A burr free lug and a cleanly machined end are signs of a high quality product with show a clean and vertical tune end.

- Correct Conductor Compression Lug Matchup

- Brand name with conductor and crimping dimensions engraved on connector

- Compatible with standards and conductor types (RE_SE_RM_SM)

Photos: Klauke

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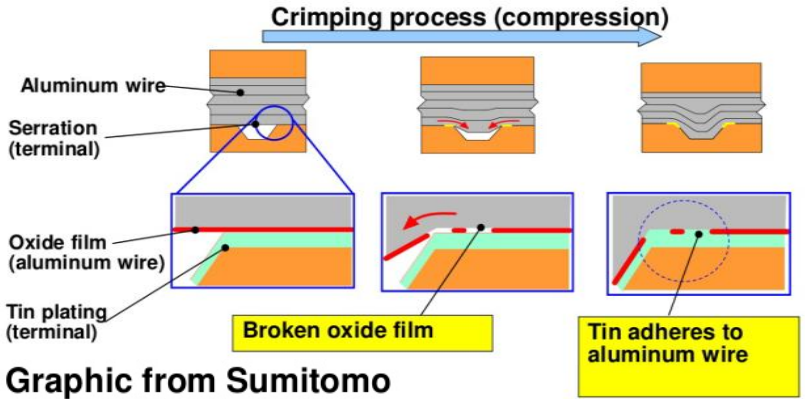
Connection, Termination, Crimping

Hexagonal or Half Moon or Dual Rated Screw

✓ Applicable for RE-RM-SE-SM Conductors
✓ Most satisfied and reliable crimping method in order to obtain ***maximum contact surface***
✓ RE&SE cross section sizes are different from RM&SM for the same cross-section
✓ Correct crimping die and force enable correct crimping depth. Also prevent joint resistance.

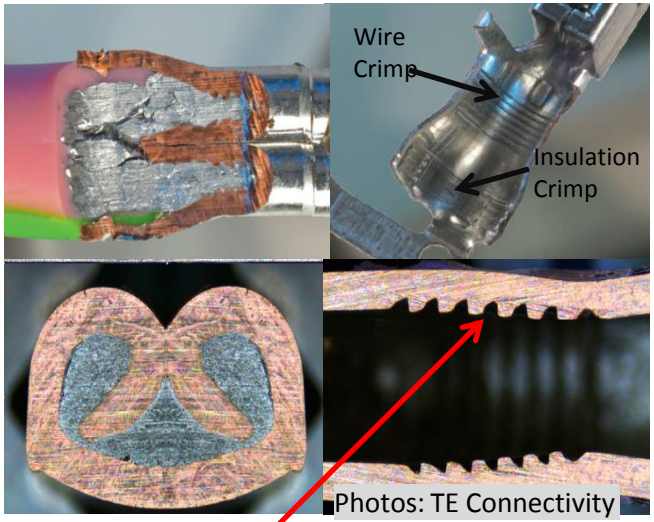
Photos: Klauke



Graphic from Sumitomo

F Crimping (Indent)

✓ For Aluminium Class 5 and 6
✓ Less Compression than Copper
✓ Sharp-Edged ***Serrations***
✓ Sonic Welding rather than Friction welding or soldering ??



Photos: TE Connectivity

Serrations

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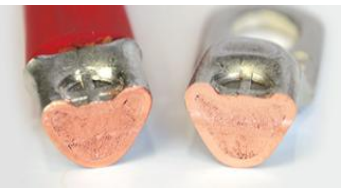
Crimping Types and Test Standards

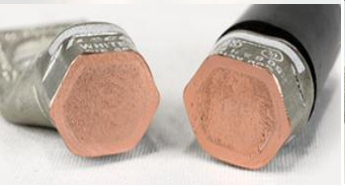
Conductor	Lug Dimensions	Equipment & Application	Test & Quality Control
EN 60228 EN 50185 ISO 6722-2 DIN 48201	DIN 46235 DIN 48083-4 EN 13600 DIN 46329 DIN 46267-2	DIN 48083-1 DIN 48083-3 UL 486 A/B	IEC 61238 EN 61238 UL 486 A/B

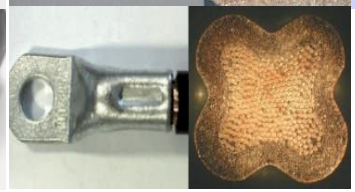
Any other crimping are applicable as long as ***compatible with standards*** and do not cause problem at ***connection points.***

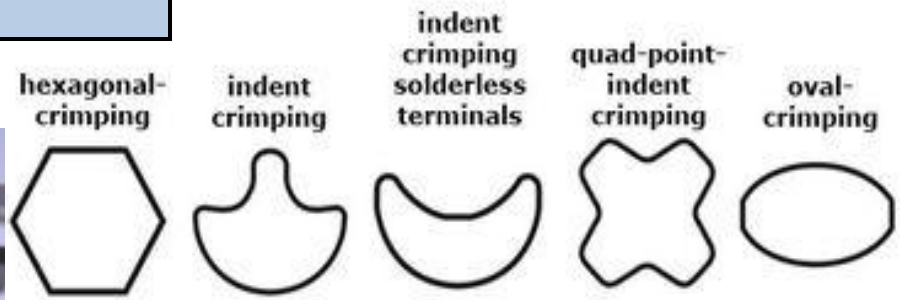
Source: TE

Source: Sumitomo









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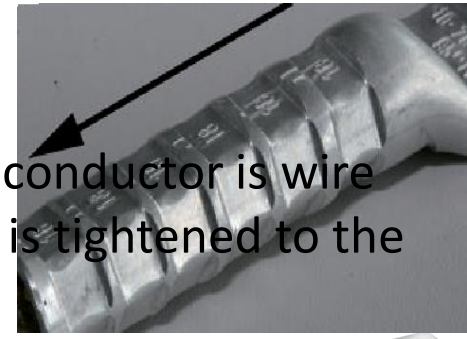
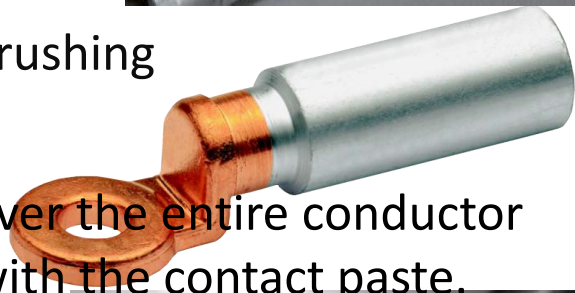
How to make a reliable connection



✓ First, the insulation is stripped. Second, the exposed part of the conductor is wire brushed. Third, an oxide inhibitor is applied. Finally, the connector is tightened to the recommended value.

✓ Brush only in one direction and not too forceful. Forceful brushing can embed oxides in the wire.



✓ Sufficient paste should be applied and distributed evenly over the entire conductor surface. Ensure surface of conductor is completely covered with the contact paste.

✓ Start the first crimp at the lug end and progress towards the conductor to ensure that compacted material expands in this direction.

✓ After crimping, a heat shrink sleeve should be applied. The purpose of this sleeve is to prevent the ingress of moisture or dirt at the junction.

"Without a Qualified Workmanship, it is a Fairy Story!!!"

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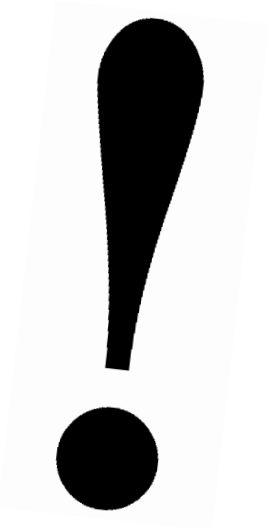
Connection, Termination, Crimping

***Small components with a great impact**, **even Fire**!!!*

- ✓ Interoperability of Accessories, Aluminium and Copper
- ✓ Workmanship Quality, Keep off Imprudent Termination
- ✓ Compound/Grease/Oxide inhibitor,
- ✓ Creep, Thermal Expansion, Voltage Drop Factors
- ✓ Material Grade of Aluminium Alloy Conductor
- ✓ Environmental Conditions
- ✓ Connector/Terminal Tools Quality
- ✓ Different manufacturer or installers have different method.
- ✓ Proper tightening torque
- ✓ Periodic inspection



Sahra Kablo

Thank you...

SELMAN ÜNLÜ
Mech. Eng, Deputy G.M.

Mail: selmanunlu@sahrakablo.com
Mobile: 00 90 532 216 64 78

Download this presentation at **www.sahrakablo.com**

Sahra Kablo