King Fahd University of Petroleum & Minerals

College of Engineering Science

Electrical Engineering Department

# EE 399

## Summer Training

## At

Jeddah cables COMPANY

# Final Report

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# I. ABSTRACT

This report discusses the summer training program at Jeddah Cables Company during the period from 3rd July 2010 to 27th August 2010. It states briefly the importance of cables and what factors are considered in cable designing process. It shows a brief background about the place of training; Jeddah Cable Company. It mentions some facts about the department that was responsible for the training program. The report describes the process of cable manufacturing at Jeddah Cable Company. Also, it explains the process of designing cables in accordance with international standards and specifications. As an example of many design problems performed during the period of training, the report contains a cable design problem. Furthermore, the report explains some cable manufacturing issues studied during the training including materials used, water blocking techniques and cable testing.

# II. INTRODUCTION

As part of the Bachelor degree for the Science Engineering students, a summer training program for 8 weeks is required to have a taste of the practical experience for engineers on the job. The training program was during the period from 3rd July 2010 to 27 August 2010 at Jeddah Cables Company – Jeddah, Saudi Arabia. This program was assigned to the Engineering Projects Department (EPD) and supervised by the Engineering Projects Manager. Engineers at EPD are responsible for designing cables according to the customer specifications and some international standards. The purpose of this report is to show the experience at Jeddah Cables Company during the summer training period.

# III. CABLES

Electricity directly serves mankind, and the electric cables form the connecting links between pieces of electrical apparatuses or machines to transmit power or signals. A well engineered cable is the product of combined efforts of many people. The cable should be capable of doing the work for which it is designed with a reasonable margin for voltage rise or current overload. Furthermore, the cable should be shielded to avoid danger to people, apparatuses and cables themselves.

Several factors affect choice of a cable including the size of the conductor, lifetime and insulation requirements and conditions. Understanding the basic elements of electrical theory and their applications is mandatory to study of the design and the usage of cables.

Cables can be classified based on the usage, the construction, the shape, the operating voltage, or other considerations.

# IV. JEDDAH CABLES COMPANY (JCC)

Jeddah cable Company is one of the leading manufacturers of electric cables and wires in Saudi Arabia. It contributes to cables industry using five plants in Jeddah which are dedicated to different jobs. These plants work together to produce five different types of cables to meet the markets demands in Saudi Arabia, Qatar and the United Arab Emirates. Jeddah Cables Company consists of nine main departments working cooperatively to achieve the company objectives.

## 4.1. JCC Plants:

### 4.1.1 Copper Rod Plant:

This plant produces copper rods using continuous casting technique with copper cathodes. This is done using cathode plates that are imported from mineral manufacturers. These plates are placed in a furnace to be fused and then shaped to cylindrical rod with the following characteristics:

- Diameter of 8 ± 0.38 mm.

- Tensile strength of 250 $N/mm^2$.
- Elongation ≥ 30%.
- Resistance of 0.01222 Ω/m
- 100% conductivity as per IACS (International Annealed Copper Standard).

  All of these specifications are measured continuously in the Copper Laboratory at the factory.

#### 4.1.2 PVC Granules Plant:

This plant manufactures various types of PVC compound to be used for insulation, bedding and sheathing the cables.

#### 4.1.3 Low Voltage Cables Plant:

This plant manufactures cables that have size range from 0.5 $mm^2$ to 800 $mm^2$ and voltage raring up to 0.6 kV (phase voltage) or 1 kV (line voltage). These cables are classified into:

- Building wires.
- Control Cables.
- Low Voltage Power Cables.
- Instrumentation cables.
- Overhead lines.

#### 4.1.4 Medium-High Voltage Cables Plant:

This plant manufactures cables that have size range from 16 $mm^2$ to 630 $mm^2$ and voltage raring up to 18 kV (phase voltage) or 30 kV (line voltage).

#### 4.1.5 Wooden Real Plant:

To manufacture wooden battens and drums used for storing and shipping cables.

### 4.2. JCC Products:

1) Low voltage power cables.
2) Medium voltage power cables.
3) Overhead lines.
4) Control cables.

5) Indoor Cables.

### 4.3. Clients:

The Jeddah Cable Company has a wide range of clients for its cables market both locally and regionally.

### 4.4. JCC Departments:

JCC internal structure is made up of a number of interrelated departments, these include: Production, Engineering and Quality Assurance, Services and Training, Business Development, Finance, Management of Information Systems, Purchasing, Human Resources and Administration and Safety.

## V. EHGINEERING PROJECTS DEPT.

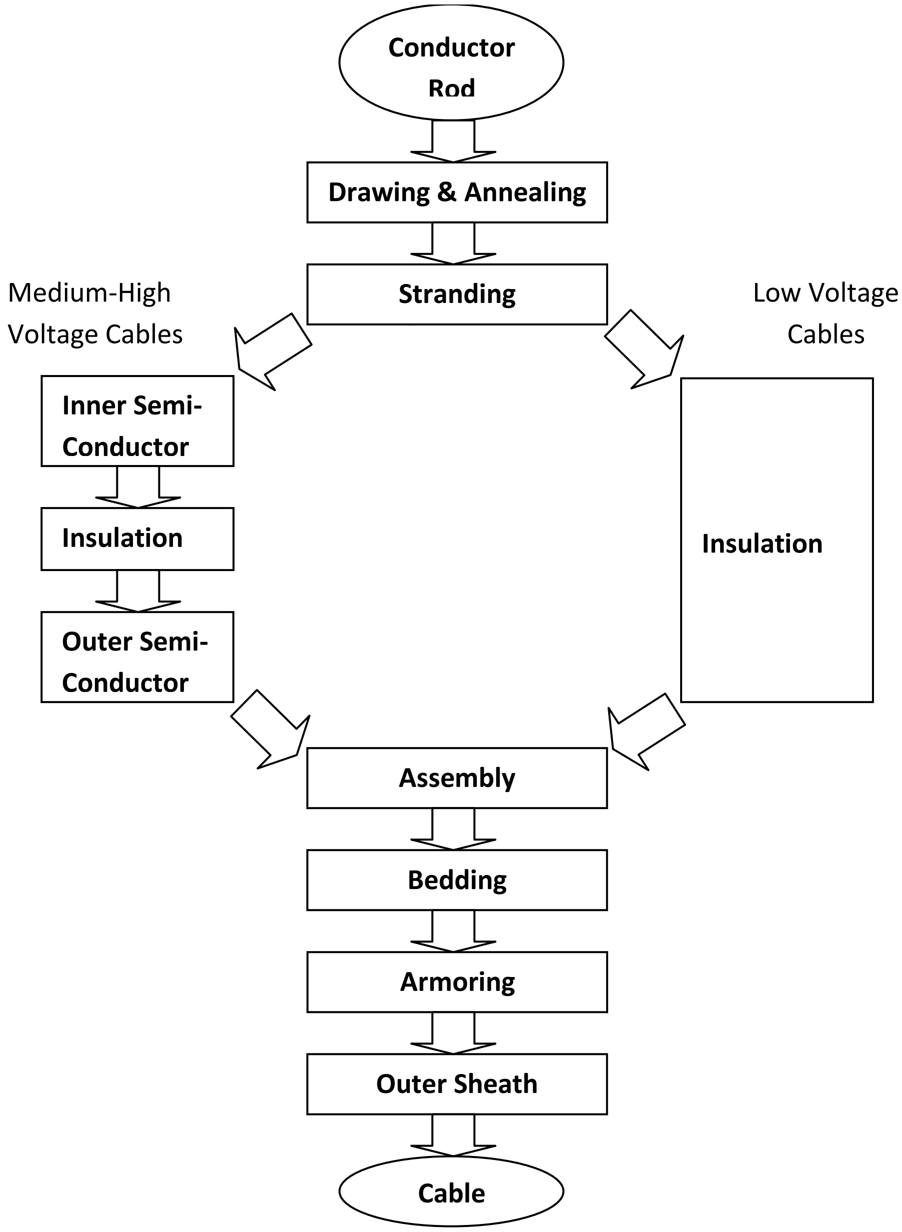
The Engineering Projects department at JCC is the heart of the company. It has many duties as following:

- It has a team of engineers who are responsible for designing cables based on many international criteria and standards which consider many cable phenomena such as resistance, inductance, conductance, capacitance, insulation, ampacity and some electromagnetic issues. Also, they have to consider the cost of raw materials used to manufacture cables to design high-quality, low cost cables.
- It ensures that the technical aspects of all production orders submitted by the sales department are correct.
- It receives from customers, such as SEC, some feedback related to the cables they have purchased to fix cables defects and solve their problems from engineering point of view. The Engineering Project department
- Its engineers represent the company at seminars, conference, committees and so on.
- It has a number of supportive duties to other departments.

# VI. MANUFACTURING PROCESS

Cable manufacturing process involves a broad range of complexity depending on the cable design to be produced. Different cable plants may be capable of a limited or broad range of designs. Then, those capable of broad range may limit operations to only a few steps in the manufacturing process. A cable goes through several manufacturing stages before exiting the factory and gets delivered to the clients as shown below:

**Flowchart of different manufacturing stages**



***(Pictures of manufacturing process stages are attached to the end of this report)***

### 6.1. Drawing and Annealing:

Copper or Aluminum rods come in standard sizes (8 mm and 9.5 mm diameter respectively) and are pulled through a series of "dies". The number of dies required depends on the final diameter, but usually varies between 6 and 13 dies. The dies are copiously lubricated by stream of suitable components to protect them against wearing out quickly. The process makes the rod longer but smaller in cross section (without any loss in total volume). This process is called "Drawing" and runs in series with another process called "Annealing" only for copper rods. Annealing is just heating the wire to provide a softer temper (more flexible). Hard temper is required for overhead transmission line. The smoothness of the wire surface depends on proper drawing techniques (well maintained dies for example) eliminates surface defects. The wires are taken up on baskets or spools for later stranding operations or on reels in the case of solid conductor cables manufacturing process.

### 6.2. Stranding:

Stranding is the process of applying several layers of conductors on top of each other (in circular manner). The advantage of doing this over just leaving large conductor is to add flexibility and easier cable terminations and joints. In addition, one cannot manufacture large solid conductors since the losses involved with such a cable (namely due to "skin effect" would be great).

Stranding layers grow through a geometric progression (i.e. by adding 6 to each consecutive layer): 1 + 6 + 12 + 18 + 24 +…etc. The JCC Low Voltage Plant does not strand more than 61 wires. This method is referred to "concentric lay stranding". There are other stranding combinations that start with centre wires greater than one and build up accordingly:

2 + 8 + 14 + 20 + 26 + 32 +…etc.

3 + 9 + 15 + 21 + 27 + 33 +…etc.

Usually successive layers are stranded in opposite directions, thus if the wires of layer have a left-handed lay, the next layer has a right-handed lay and so on. However, the most top layer must be a right-handed lay and each layer below is in the opposite direction of the other.

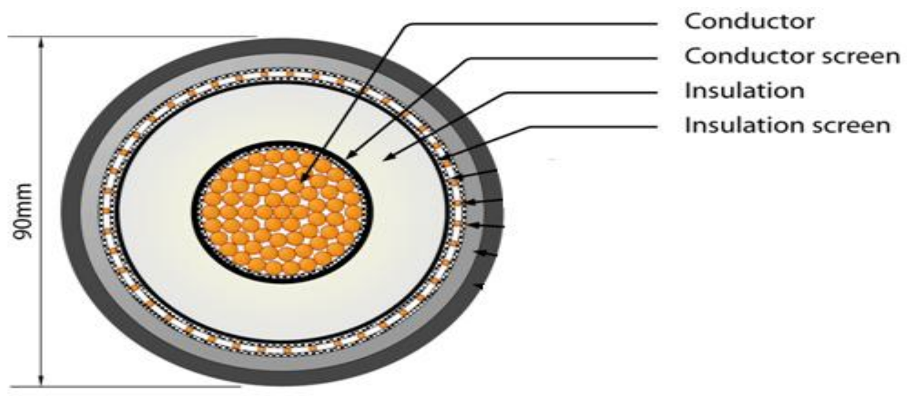
Stranded conductors are made on machines known as bunchers or stranders. The type of machine used for this purpose depends on the characteristics of the wire.

The machines used at JCC for stranding purposes are:

- Bow Twisters: suitable for stranding insulated conductors.
- Planetary Stranders.
- Rigid Stranders.

## 6.3. Insulation:

This is the process of adding a non-conducting layer on the top of the conductor by means of extrusion. The extruder adds one insulating material layer on the top of the conductor in the case of Low Voltage Cable manufacturing process. However, this is not the case for Medium Voltage Cable manufacturing process. In fact, the extruder adds three layers at a time on the top of the conductor. The other two layers are made of a semi-conductor material. The insulation material is always in between of the two semi-conducting layers. The inner semi-conductor layer is called "conductor screen" and the outer one is called "insulation screen" as shown below:



The purpose of the inner semi-conductor layer is to smooth out the surface irregularities of the stranded conductor, thus reducing the level of electric field that exists outwards.

The purposes of the outer semi-conductor layer are:

- To equalize the electric field comes out of the insulation.
- To prevent the electric field of the conductor from coming out as much as possible.
- To protect the conductor from the external fields as much as possible.

### 6.4. Screening:

Screens are compulsory for all cable types above 0.6/1 kV. Screens usually consist of copper tapes or copper wires. In case of multi-core cables, individual core screens may have individual screened cores or a common screen. The purposes of the screens are the following:

- Potential grounding and limiting of the emanating electric field.
- Conductor of charge and discharge currents due to short circuit or induced voltage.

### 6.5. Assembly:

This is the process of placing several cores or phases together and putting non-hygroscopic fillers in the spaces between and around the cores. This is done in spiral manner, with designated lay length similar to that of stranding, using a laying up machine or drum twister. Everything is banded together with binder tape, which is wrapped around the assembled cores in a helix manner (with certain % in overlap) to give a more compact shape-form.

### 6.6. Bedding:

It is the process of extruding lower quality PVC or PE on the top of the binder tape to protect the cores from the armoring that comes later. However, there is no need for bedding in the case there is no armoring.

### 6.7. Armoring:

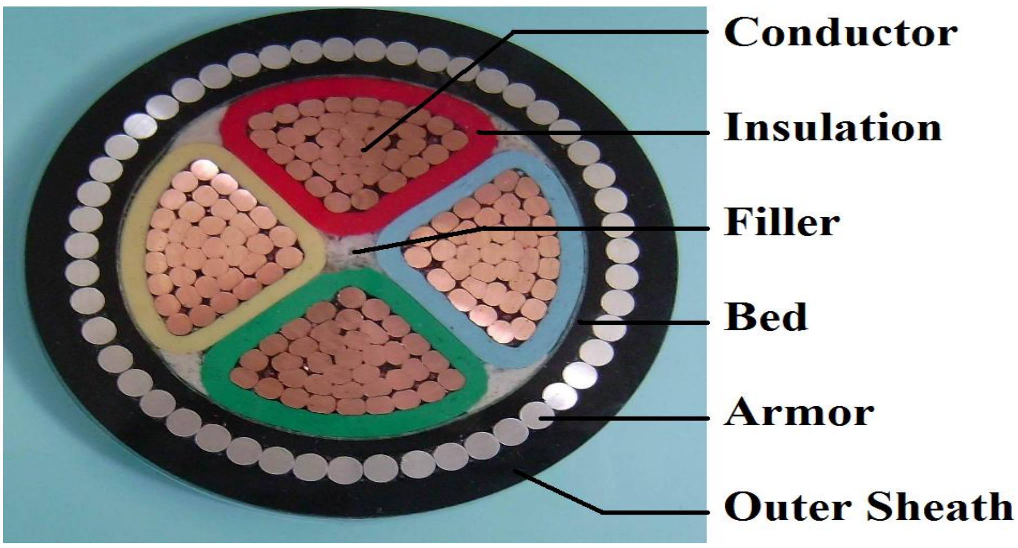
This comes in the form of steel wires or steel tapes for multi-core cables. The purpose of armoring is to protect the cable from external blows or shocks that would otherwise damage the cable cores.

### 6.8. Sheathing:

Sheathing is the process of extruding a protective layer on the top of the armors. In fact, it is the visible part of the cable and it contains the cable identification (the manufacturer name, cable type, cable voltage…etc). The sheath is usually made from soft temper PVC or PE with any type of color.

## VII. CABLE DESIGNING

To design cable, the Engineering Projects department at JCC carries out many steps:




### 7.1. Conductor Design:

There is a strict relationship governing conductor size and resistance, in that the resistance is inversely proportional to the cross section area of the conductor. Thus, increasing the area leads to decreasing the resistance and increasing the material cost from financial point of view. The greater the cross sectional area, the greater initial outlay.

So, from economical point of view the determining of the sizes is a standard problem for engineers.

The conductor cross section shapes can be divided into five main types: Stranded Round Circular, Stranded Compacted Circular, Stranded Sectoral, flexible and Solid.

Each of these cross section shape has its own applications and design calculation that consider the resistance, the wires diameters, the number of wires, the stranding lay length, the assembly lay length and the weight of the conductor.

All of these specifications calculation are performed on the light of some international standards that are required by the client such as IEC 60228, ASTM B 231/B 231M-04, ASTM B 232/B 232-01 and the like.

## 7.2. Insulation Design:

To design insulation, we have to know two main specification of the conductor:

- The operating voltage.
- The cross sectional area.

In this stage, electrical engineers have to decide the proper thickness of the insulating material will be used with considering the minimum thickness, some tolerance, some electromagnetic calculations and some the cost of the material used. The type of material used for insulation is determined by the client or the international standard used in some cases.

## 7.3. Screen Design

As mentioned before, screens are conducting metallic layer on the top of the insulation to discharge the short circuit current at a short period of time. There are two main types of screens manufactured at Jeddah Cables Company:

- Copper wires with a copper tape with open helix.
- Two copper tapes with overlap.

Engineers need to know two requirements from the client:

- The maximum short circuit current that screen can carry.
- The maximum duration that discharging could last.

### 7.4. Assembly Dimensions:

In this stage of cable designing process, the diameter of the overall assembled cores and the assembly lay length are considered. These dimension calculation should be performed as mentioned in some international standards.

### 7.5. Thickness of extruded bedding material:

Depending on the assembly diameter and the cores (conductors with insulation) diameters, the thickness of the extruded bedding material is calculated with help of the fictitious method calculations.

### 7.6. Armors Dimensions:

The number of armoring wires or tapes and their dimensions are calculated after performing the last steps correctly. Engineers use tables in the used standard and the fictitious method again in this step to find the number of armoring wires and the diameters of them.

### 7.7. Thickness of the external sheath:

In this stage, the thickness of the visible part of the cable is calculated. Again, engineers should know the last dimensions calculations performed in the last steps. Then they use the standard with some fictitious method calculations to find the thickness of the sheath.

These are the steps performed by the team of electrical engineers team to design cables matched by the client desire and on the light of some famous international standards.

During this summer training program, I participate in many cable design problems.

# VIII. CABLE DESIGN PROBLEM

In this part, one cable design problem will be discussed and solved as one example of what I have designed during the summer training period.

**The cable specifications:**

4x10 $mm^2$/ Cu / XLPE / SWA / PVC / (0.6/1 kV) (1.2 kV) – Stranded Round Circular – IEC / [Adiabatic short-circuit current = 2kA for 1 second]

**The explanation:**

The cable is to be designed has the following properties:

No. of cores: 4.

Cross section area of conductor: 10 $mm^2$.

Cross section area shape: Stranded Round Circular.

Conducting material: Copper

Insulating material: XLPE (Cross Linked Polyethylene)

Armor: Steel Wire Armor (SWA)

Sheathing material: PVC (Poly-Vinyl Chloride)

The operating voltage = 0.6 kV ph-ph/ 1 kV L-L

The maximum operating voltage = 1.2 kV L-L

The international standard: (IEC 60228) & (IEC 60502-1)

The cable screen can carry a short circuit (fault) current of 2 kA for 1 second at adiabatic conditions (no heat transfer).

## The designing steps:

- **Conductor**:

  From the IEC 60228 standard, the conductor should have the following:

  Resistance = 1.83 Ω/km

  Resistivity (p)= 17.241

  No. of wires (nw)= 7

  So, we to find the wire diameter (dw):

  The stranding factor ($K_S$) = 1.2 (given)

  The Assembly factor ($K_A$) = 1.3 (given)

  dw = $\sqrt{p.Ks.K.4/(\pi.nw.R)}$ = $\sqrt{17.241x1.2x1.3x4/(\pi 7x1.83)}$

  = 1.635 mm + 0.2 mm (to reduce the effect of tolerance

  So, the designed diameter of one wire should not be less than 1.635 mm to keep the resistance within the allowed range.

  The weight of copper used = π*0.25*$dw^2$* nw* Ks* Ka* N*dens

  = π*0.25*$1.835^2$* 7* 1.2* 1.3* 4*8.96

  = 564.03 kg/km

- **Insulation:**

  From the IEC 60502-1 standard, the nominal thickness of insulation for a 10 $mm^2$-cross sectional area, copper conductor should be: 0.7 mm and the minimum thickness

  = 0.9 $t_n$- 0.1 = 0.53 mm

  So, the diameter of the core = 3 dw + 2 tn

  = 1.835 * 3 + 2 * 0.7 = 6.9 mm

- **Screen:**

  The type that will be used in this cable is the one called "Copper wires with a copper tape with open helix".

  So, the purpose of this step is to determine the diameter of wires, the number of wires and the thickness and the width of tape.

  The given requirements are:

  Adiabatic short circuit current = 2000 A

The duration of discharging = 1 sec

The designing steps:

**1)** Finding the geometrical cross section area (S) of the combination of the tape and wires according to the equation:

$Isc^2$ x t = $K^2$ x $\underline{\mathbf{S}}^2$ x ln ( $(\Theta_f+\beta)/(\Theta_i+\beta)$) , where

Isc = short-circuit current = 2 kA

t = duration of discharging

K = constant depending on the material (Cu = 226)

$\Theta_f$ = final temperature

(According to the IEC60502-1, XLPE = 250$^o$C)

$\Theta_i$ = initial temperature

(According to the IEC60502-1, XLPE = 90$^o$C)

So, from the last equation and its known variable, we get:

S = 13.978 $mm^2$

JCC uses copper tapes with thickness of 1 mm and width of 15 mm.

**2)** To calculate the diameter and the number of wires:

S = [0.25 x $\underline{\mathbf{n}}$ x π x $\underline{\mathbf{d}}^2$ + t x w] x N, where

n = number of screen wires.

d = diameter of screen wires.

t = thickness of the tape.

w = width of the tape.

N = number of cores.

Since we have two variables in the equation, we use an Excel Sheet Calculation to make a trade of between the number of wires and the diameter of one screening wire that give us the minimum weight of the screening copper.

=SQRT((J4^2*J5)/(J6^2*LN((J7+J9)/(J8+J9))))*1000

| L | K | J | I |
|---|---|---|---|
| Trainee Name : | Mamdouh Al-Harbi | | |

| | | |
|---|---|---|
| IAD | 2 | kA |
| t | 1 | sec |
| K | 226 | |
| θi | 250 | ºC |
| θf | 90 | ºC |
| β | 234.5 | |
| N | 3 | |
| S | 13.978 | mm^2 |
| th | 0.1 | mm |
| w | 15 | mm |
| D,ows | 26 | mm |
| δ of copper | 17.241 | Kg/km.mm^2 |
| ka | 3.0603 | |
| k2 | 0.15 | |

| nw | dw | W,wire | W,tape | W,total |
|---|---|---|---|---|
| | mm | Kg/km | Kg/km | Kg/km |
| 1 | 2.01 | 166.69 | 74.58 | 241.28 |
| 2 | 1.42 | 166.69 | 71.66 | 238.36 |
| 3 | 1.16 | 166.69 | 70.37 | 237.06 |
| 4 | 1.00 | 166.69 | 69.60 | 236.29 |
| 5 | 0.90 | 166.69 | 69.07 | 235.76 |
| 6 | 0.82 | 166.69 | 68.68 | 235.38 |
| 7 | 0.76 | 166.69 | 68.38 | 235.07 |
| 8 | 0.71 | 166.69 | 68.14 | 234.83 |
| 9 | 0.67 | 166.69 | 67.94 | 234.63 |
| 10 | 0.63 | 166.69 | 67.77 | 234.46 |
| 11 | 0.60 | 166.69 | 67.62 | 234.31 |
| 12 | 0.58 | 166.69 | 67.49 | 234.18 |
| 13 | 0.56 | 166.69 | 67.38 | 234.07 |
| 14 | 0.54 | 166.69 | 67.28 | 233.97 |
| 15 | 0.52 | 166.69 | 67.19 | 233.88 |
| 16 | 0.50 | 166.69 | 67.11 | 233.80 |

| | | |
|---|---|---|
| Mininmum Weight | Kg/km | 233.80 |
| Related number of wires | | 16 |

- **Assembly Diameter:**

  The assembly diameter is the diameter of the combination of the four cores, the filling material and the tape that collect them together.

  Assembly diameter = core diameter * $K_{IEC}$

  = 6.9 * 2.42 = 16.7 mm

  To perform the other stages of designing, engineers should perform some external calculations called "The Calculation Fictitious Method".

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**The Fictitious Calculation Method:**

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Dc = fictitious core diameter

Df = fictitious assembly diameter

Db = fictitious diameter over bedding diameter

Dx = fictitious diameter over armoring

Tb = fictitious thickness of bedding

Dc = dl + 2ti = 3.6 + 2 x 0.7 = 5 mm

Df = $K_{IEC}$* Dc = 2.42 x 5 = 12.1 mm

Tb = 0.4 mm because Df < 40 mm

Db = Df + 2Tb = 12.1 + 2 x 0.4 = 12.8 mm

Dx = Db + 2Tb = 12.9 + 2 x 1.25 = 15.4 mm

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- **Thickness of extruded bed:**

  Considering Df = 12.1 mm as found in the last calculation method and using table 8 in the IEC 60502-1 standard, it is found that: The thickness of bedding material = 1 mm.

- **Armor Diameter:**

  Using the given value of Tb and table 9 in the IEC 60502-1, it is found that:

  The armoring wire diameter = 1.25 mm

- **Thickness of Sheath:**

  The thickness of sheath = 0.035 Dx + 1

  = 0.035 (15.4) + 1 = 1.5 mm

  The minimum thickness = 0.8 (1.5) – 0.2 = 1 mm

  To sum up,

  The final cable diameter

  = Ass. Dia.+ 2 x bed thick. + 2 x Armor Dia. + 2 x sheath dia.

  = 16.7 + 2 x 1 + 2 x 1.25 + 2 x 1.5

  = 24.2 mm

# IX. MATERIALS USED

The different stages of manufacturing require different raw materials as described below:

### 9.1. Drawing and Annealing:

Copper: High conductivity and greater flexibility after annealing. Can be drawn to small sizes and bunches for excellent flexibility. Aluminum: Lighter in weight and cheaper in price than copper.

### 9.2. Inner semi-conductor (conductor screen):

Bondable semi-conducting polyethylene, colored black.

### 9.3. Insulation:

There are basically three major types of insulating materials that are used in the insulation manufacturing process in Jeddah Cables Company. These are:

- PVC (Poly-Vinyl Chloride).
- XLPE (Cross Linked Polyethylene).
- Vulcanized Rubber: EPR (Ethylene Propylene Rubber).

### 9.4. Outer semi-conductor (insulation screen):

Bondable semi-conducting polyethylene, colored black.

### 9.5. Screening:

Copper tape and/or wires, because they can act as the neutral for each unique phase (shorted together for increased surface area capacity).

### 9.6. Assembly:

Polypropylene fillers, Polypropylene Tape and Mylar Tape are all non-conducting and help to fill the space without adding lots of weight.

### 9.7. Bedding:

The materials used are PVC or PE (just like insulation but of lower quality).

### 9.8. Armoring:

The minerals used are Aluminum wire or tape, or steel wire or tape.

### 9.9. Sheathing:

The materials used are:

- PE (Polyethylene).
- LDPE (Low Density Polyethylene).
- HDPE (High Density Polyethylene).
- LLDPE: (Linear Low Density Polyethylene).

# X. WATER BLOCKING TECHNIQUES

If water or moisture is allowed to build up inside a cable, then this will have devastating effects on the cable lifetime and its ability to perform its tasks safely. Electrically speaking, water in its impure form conducts electricity and as a result, the cable temperature will increase significantly when carrying current. However, water itself does not affect the mechanical properties of the polymer but the insulation efficiency will be dropped.

To prevent water from building up inside the cable, some materials are used:

- Cellulose based materials.
- Acryl amides.
- Polyacrylics.

The common property of all these materials is that they swell when they come in contact with water. Forming the swells is the mechanism for providing blocking against water horizontally.  However, we use aluminum or polyethylene tapes to prevent water from entering the cable vertically.

# XI. CABLE TESTING

There are basically three stages in testing:

1. Raw material testing: checking the quality of materials imported to Jeddah Cable Company.
2. In process testing (Quality Assurance).
3. Final product testing (Quality Control).

There are three major categories of testing that take place on the cables as specified by the International Electro technical Commission:

- Routine test: carried out the entire manufactured full length of cable and these include measurement of the electrical resistance, voltage test and partial discharge test.
- Sample test: which involve conductor examinations, check of dimensions, and hot set test for XLPE insulation.
- Type test: which check if a 10 to 15 meter length of a cable complies with standard characteristics or not.

# XII. CONCLUSION

Working for Jeddah Cables Company gave me a great experience in electrical cables industry in Saudi Arabia. It was a nice opportunity to gain a valuable background in cable manufacturing process and the market of such products. This summer training period enabled me to work with a professional team of well-qualified, multi-nationality, electrical engineers. The process of designing depends on many electrical courses I have been taught at the university. It was clear that working for companies as an engineer makes him responsible for taking critical decisions. Also, the team work skills are very significant for employees who work in projects.

# XIII. TABLE OF MANUFACURING FIGURES

**Figure 1: Unprocessed Copper Rod**

**Figure 2: Drawing and Annealing**

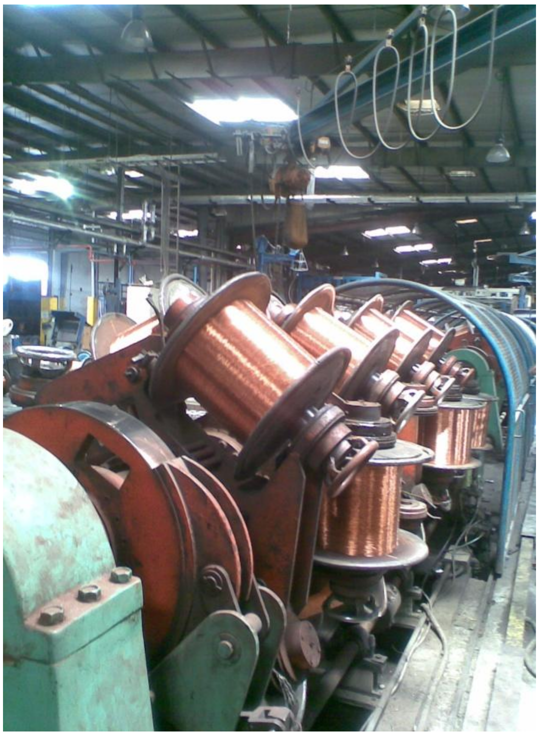

**Figure 3: The Stranding Stage**

**Figure 4: The Insulating Stage**

Figure 5: Screening Stage

Figure 6: Screened Core

Figure 7: The Assembly Stage

Figure 8: The Fillers Used

**Figure 9: Cable After Bedding Stage**

**Figure 10: Armoring Stage**

**Figure 11: Armored Cable**

**Figure 12: Final Cable Products after Sheathing**