SIMCO

Tailored Insulations for High Transmission Rate Data Cable

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ABSTRACT

Even with the spread of fibre optical cables into the communication access network, copper symmetrical twisted pair data cables are still at the forefront of today's designs. As transmission rates increase, older "multi-purpose" insulations may not meet these new demands. Recent tailored solid polyethylene (PE) and polypropylene (PP) formulations for unscreened twisted pair (UTP) cables have provided some distinct advantages for the cable manufacturer. Foamed PE for screened data cables has seen recent advances in the quality of these insulations for Category 7 and Category 7A designs. Physical foaming insulations specifically designed for data cable can now allow manufacturers to optimise their line speeds and minimise scrap rates.

This presentation will focus our experience with an optimised range of solid and foamed data cable insulation materials and a new enhanced PP solid insulation for Cat 6A designs.

Keywords: data, insulation, solid, foam

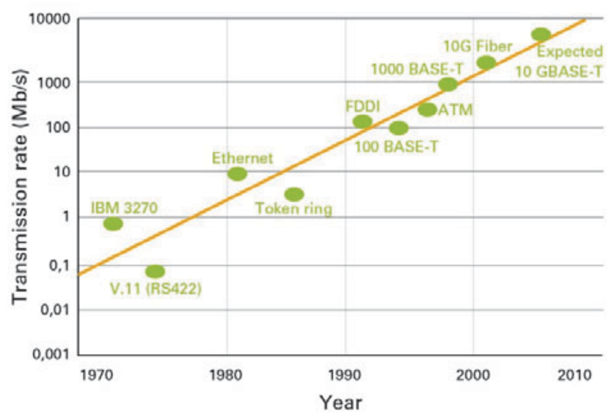

Figure 1. Evolution of data transmission rates

Introduction

Historically the first data cable designs evolved from symmetrical multi pair telephone cable or coaxial radio frequency designs, but soon the 4 pair symmetric design became the design of choice for data cables. These cables were initially used to link computer systems together in Local Area Networks (LAN) but now are used for commercial networks, industrial cabling and residential cabling.

As the transmission demands have increased so has the data cable operating frequencies. Data cables are therefore categorised according to their working frequencies. The vast majority of data cables installed today are category 6 through to category 7a however newer designs to transmit more data over potentially shorter lengths will operate at 2000MHz or higher.

Category	Operating frequency
Category 3	16 MHz
Category 4	20 MHz
Category 5e	100 MHz
Category 6	250 MHz
Category 6a	500 MHz
Category 7	600 MHz
Category 7a	1000MHz
Category 8	2000 MHz

Figure 2. Data cable categories and operating frequencies

Data cable principle design requirements

For category data cables there are two generic types of data cable design: unshielded twisted pair (UTP) and shielded twisted pair designs. These are described below in Figure 1.

Acronym	Full name
UTP	Unshielded Twisted Pairs
FTP	Foil Twisted Pairs
S/FTP	Screened / Foil Twisted Pairs
S/STP	Screened / Screened Twisted Pairs

Figure 3. Acronyms for unshielded and shielded data cable designs

Several electrical parameters are crucial to monitor to ensure a fit for purpose data cable.

1. Characteristic impedance

This is defined as sum of all effects that will impede/inhibit the flow of electricity along the cable. It combines inductive and capacitance (reactive effects) with resistance.

The characteristic impedance is a function of the insulation permittivity (dielectric constant) and the cable geometry and is determined by size and spacing of the respective conductors in the pair and the type of dielectric between them.

Theoretically impedance is independent of frequency and shielding strongly reduces the impedance. Foamed insulation with lower permittivity is therefore necessary for shielded designs in order to achieve the required dielectric properties within a given insulation diameter.

Unshielded Pair Impedance

$$Z_0 = \left[\frac{276}{\sqrt{\varepsilon}}\right]\log\left(\frac{2s}{d}\right)$$

Shielded Pair Impedance

$$Z_0 = \left[\frac{276}{\sqrt{\varepsilon}}\right]\log\left(\left(\frac{2s}{d}\right)\left(1+\left(\frac{s}{2h}\right)^2\right)^{1/2}\right)$$

Parameter definitions

- Permittivity of dielectric **(ε)**
- Conductor diameter **(d)**
- Conductor separation **(s)**
- Distance between balanced pair and ground **(h)**

UTP designs such as cat 6a and below therefore required a solid insulation and shielded designs such as cat 7 and 7a require a foamed insulation.

2. Return loss

Return loss is a measure of the reflected signals produced by variations or discontinuities in the cable structure in relation to the signal sent, i.e. it is a measure of the reflected energy from a transmitted signal. In a cabling system, return loss also reflects mismatches in the components of the cabling system, including cables, connectors and panels.

3. Internal crosstalk

This is the unwanted coupling of signals in adjacent or nearby pairs within a cable. Several different types of crosstalk have been defined. When the degree of reduction in signal strength in the disturbed pair is measured at the same end as the signal input in the disturbing pair, it is called near-end crosstalk (NEXT). Far end crosstalk (FEXT) refers to the measuring of the unwanted signal coupling between pairs in the same cable when the disturbing signal is measured at the receiving end. Both types of crosstalk are related to interference within one symmetric data cable.

The effect of this unwanted coupling can be controlled or even eliminated by destructive interference between the fields generated by each wire. This is achieved by twisting together the send and return legs of a pair. Similarly, the twist also causes cancelling currents to flow in receiving pairs. However, the twist must be different between interacting pairs, to prevent cumulative coupling occurring at regular intervals along the length of the cable.

Shorter lay lengths due to tighter twisting of data cable cores will improve crosstalk but the practical implications in the manufacturing steps can be significant especially with cellular insulation cores that are less resilient than the solid cores in the twinning and twisting processes.

4. Alien Crosstalk

This characteristic quantifies the unwanted signal coupling between one or more pairs from one symmetric data cable to an adjacent disturbed data cable.

The most effective route identified for minimizing the effect of alien crosstalk is the shielding of pairs, individually or all together.

5. Attenuation

Attenuation (α) is defined as the loss in power of an electrical signal, i.e. decrease of signal amplitude as it travels along a pathway. This signal loss is due to limited conductivity of the conductor and dielectric losses.

The following equation may be used to calculate attenuation for an unscreened pair.

$$\alpha = A\left(\frac{1}{d\log\left(\frac{2s}{d}\right)}\right)\sqrt{f}\sqrt{\varepsilon} + Bf\tan\delta\sqrt{\varepsilon}$$

- **A& B** are constants
- Frequency **(f)**
- Permittivity of dielectric **(ε)**
- Conductor diameter **(d)**
- Conductor separation **(s)**

The attenuation defined in decibels (dB) is exponential with respect to the cable length. In addition, the attenuation is very dependent on the frequency of cable operation and the dielectric losses are of increasing importance with increased frequency.

The next table summarises the variables that can influence a particular electrical property. Some of them have a direct relationship to the dielectric permittivity and even those influential parameters that have a geometric aspect are indirectly influenced by the choice of insulation. Processability and crush resistance will all play a part in the final geometry of the twisted pairs.

Electrical property	Influential parameter
Impedance	**Dielectric insulation** • Permittivity • Conductor separation • Conductor adhesion **Cable design** • Conductor spacing • Conductor size
Return loss	**Manufacture** **Impedance (consistency)**
Crosstalk	**Cable design** • Twisting • Shielding
Attenuation	**Frequency** **Dielectric insulation** • Permittivity • Dissipation factor **Cable design** • Total length • Shielding • Conductor size • Insulation thickness

Data cable insulation cores

At first sight one could ask then why foam an insulation but the key is the decrease in permittivity as the foaming degree increases as illustrated in Figure 4.

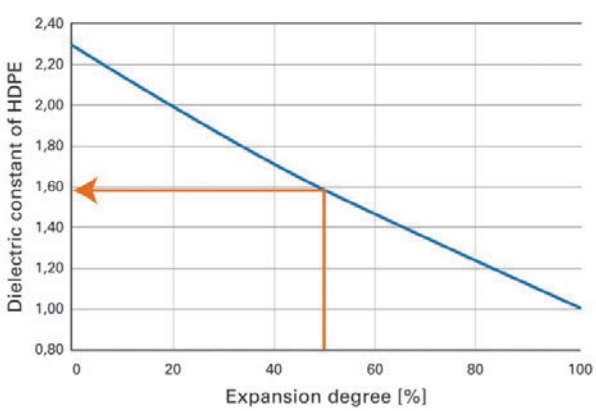

Figure 4. Permittivity (dielectric constant) versus expansion degree for HDPE

There are four generic insulation designs for manufacturing telecommunication cable insulation, but only two of which are commonly used today for data cable i.e. the solid and the skin/ foam/skin designs.

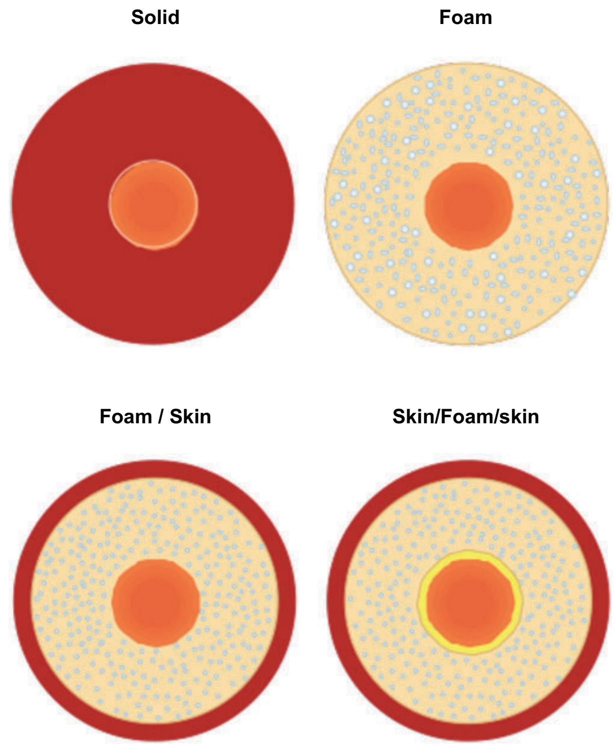

Figure 5. Insulation core types

Foamed insulations are manufactured in one of two ways: chemically or physically foamed.

Chemically foamed insulation compounds contain a blowing agent that is activated during the extrusion and thereby releasing a gas which can result in maximum insulation expansion levels up to 45-50%.

Physically foamed insulation is achieved through the gas injection process. Today, the vast majority of foamed data cable is Skin/ Foam / Skin design using a triple head gas injection line. A gas injection point in a physical foaming insulation extruder ensures higher expansion level possibilities to lower the permittivity even further than in conventional chemically foamed telecom cores. Optimal material selection can then achieve S/F/S data cable designs with expansion levels between 35- 65%.

Data cable insulation material requirements & properties

Due to the fundamental design requirement of equidistant conductors and the resulting mechanical stresses imposed on the cores during the complete cable manufacturing process; high deformation resistant insulations are a prerequisite to any good data cable.

Polyethylene (PE) and to a lesser extent polypropylene (PP) are used today for category data cable insulations. Both have intrinsically low dielectric constants and careful selection can ensure that they have excellent conductor adhesion and good crush resistant properties.

The insulation must exhibit good and consistent conductor adhesion as varying adhesion levels will cause geometric imbalances in the core, thereby destroying the data cable's electrical performance. Traditionally, the lower the PE density the better the conductor adhesion, however, the latest HDPE insulations designed specifically for data cable have even better adhesion properties than conventional low density compounds historically used in telephone wire. HDPE insulations have the added benefit of mechanical strength and good Shore D hardness properties to provide protection to the cores during the twinning and twisting manufacturing steps.

PP insulations used for data cable insulation generally exhibit good mechanical properties and the latest PP to come onto the data cable market also has very good adhesion properties.

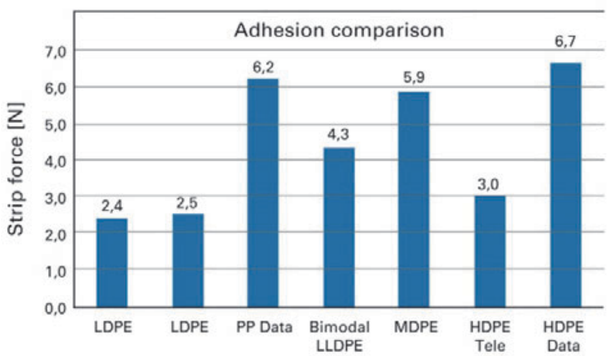

Figure 6. Relative conductor adhesion properties using ASTM D 4565, part 19:2004. Conductor Preheater at 140°C for PP and 100°C for the other PE grades

Conductor adhesion is critical for solid UTP designs, but perhaps even more so for skin/ foam/ skin designs. In such designs the inner conductor skin separating the conductor from the foam can be as little as 20micron thick and needs to be consistently applied at line speeds of up to 1800 m/min.

For foamed insulation, the bubble size and consistency is key to a shielded data cables' electrical performance. Careful selection of the insulation compound and compatible inner and outer skin materials is the first step, and learning how best to process the compound on each particular gas injection line is also crucial to achieving the optimal foam structure. The best foamed insulations have thin inner and outer skins, which are of a constant thickness encompassing a strong homogeneous foam structure full of small, fully formed bubbles that provide crush resistance during the downstream twinning / twisting processes. Such an example is as illustrated in figure 7.

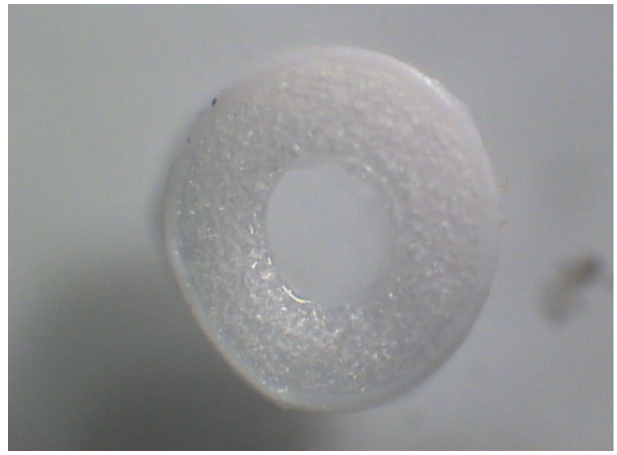

Figure 7. Skin/foam/skin cross section with tailored HDPE skin layers encapsulating homogeneous HDPE foam

PP can also provide some other benefits, which are becoming more attractive as data cables continue to increase in frequency in order to transmit more information. Individual cores will still be manufactured to geometric tolerances of > 95% but tighter lay lengths will be needed in UTP designs to avoid alien crosstalk and thus more crush resistant insulation materials will be required.

The conductor diameters will probably increase to maintain the impedance, thereby higher frequency UTP cable could become bulkier and less easy to install. Potential downsizing of these the insulation by using PP could be a possibility.

Newer applications such as power over the internet will mean potentially higher operating temperatures and thereby the selected insulations need to be suitably protected, but still retaining their intrinsic insulation capabilities.

	Unit	PP	HDPE
Density	kg/m3	912	945
MFR2 (230°C)	g/10min	3.0	-
MFR2 (190°C)	g/10min	-	0.7
Dielectric C	At 1MHz	2.26	2.32
Shore D 15sec		70	58
Tensile strength*	Mpa	56	35
Tensile Elongation*	%	780	700

Table 8. Comparison of critical material properties for a Solid PP and HDPE data cable insulation

* Performed on stripped cable isolation, Cu 0.53mm / OD 0.94mm

PP processing at has the reputation of being more difficult that HDPE and this can be the case, but with the use of optimised temperature profiles and tooling this issue can be resolved. To illustrate we extruded both solid PP and HDPE data cable insulations on a pilot line.

Data core construction: 0.53 mm copper diameter & 0.94 mm outer core diameter.

Extruder type: Francis Shaw (licence Davis Standard) 63,5mm, 22 L/D with a medium compression screw with no mixing devices. Drive was 40bhp (29, 8 kW) geared to 100rpm maximum screw speed

Reference HDPE data cable insulation was extruded at approximately 1000m/min with a screw speed of 54 rpm. Using the same tooling, and a conventional gradient PP temperature profile we could maintain 1000m/min but at the machine maximum of 100rpm. The screw output per revolution (specific output) of the PP was lower than the HDPE and in order to increase the line speed further we had to address this. This was done by using a reverse temperature profile shown in table 9 and now a reduced screw speed of 81rpm was required to reach 1000m/min.

The next step was to modify the die and we increased the die diameter from 0.95 to 1.00 mm and the die body length from 25 mm to 30 mm. These die modifications in combination with the reverse temperature allowed the PP specific output to increase further and only 51rpm were required to achieve 1000m/min.

Material	Extruder Temperature Profile [°C]	Die Length & Diameter	Extr. Press. [bar]	Line Speed [m/min]	Screw Speed [rpm]
HDPE Data	220-240-230-210	(25mm & 0.95mm)	460	1025	54
impact of processing parameters					
PP DATA	170-190-200-170	(25mm & 0.95mm)	490	1000	100
PPDATA	220-240-230-210	(25mm & 0.95mm)	409	1016	81
impact of die size					
PP DATA	220-240-230-210	(30mm & 1mm)	266	1006	51

Table 9. Pilot line study to optimise PP line speed

Conclusions

By using tailor made insulations robust data cable designs are possible that not only meet the increasing transmission demands, but can be produce at the fast line speeds used on the newest data cable insulating lines.

Superior conductor adhesion is critical for a data cable's performance and the development of tailor made HDPE for solid insulation for UTP designs has ensured excellent adhesion along with a mechanical resilience during manufacture.

This HDPE data cable insulation is unique in that it is also successfully used as both the inner and outer skin of skin / foam/ skin insulation used for physically foamed shielded designs. These cores are mechanically stronger to face the downstream mechanical forces exerted on the insulated wires as they are twinned and twisted into 4 twisted pairs. The use of just one skin material for both layers simplifies the insulating line material logistics.

A new PP insulation specifically designed for UTP cable satisfies the superior adhesion requirements, and the extra mechanical robustness allows for new smaller lay length designs to be manufactured.

Finally the current generation of physical foamed HDPE is providing the process stability and fine and homogeneous cell structure that are required to produce cat 7 and Cat 7a cores at speeds of 1500m/min or more. This material is also supporting the realisation of new Cat 8 designs.