CONDUCTIVE COMPOUNDS

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CABELEC® Compounds Processing Guide

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Introduction

CABELEC compounds are a range of compounds that are electrically conductive thereby reducing the risk of electrostatic discharge. The conductive properties of the compounds are permanent. CABELEC compounds are based on a large variety of thermoplastic polymers and are designed to fulfil specific requirements related to electrical, rheological and mechanical properties. A range of CABELEC compounds is available for different processing techniques such as blown film extrusion, sheet and profile extrusion, injection moulding, blow moulding, etc.

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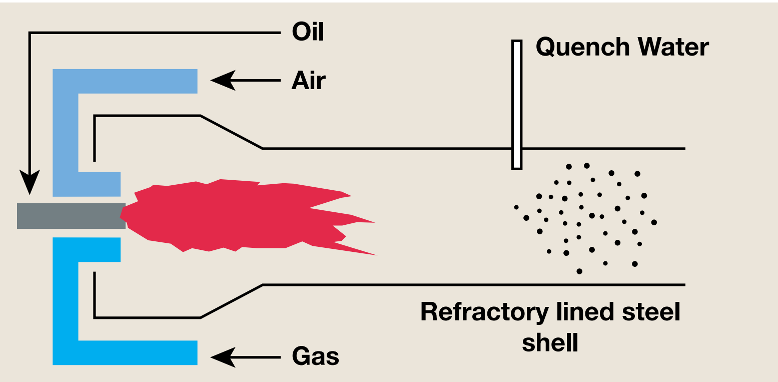
CABELEC® Compounds Processing Guide

Conductive carbon black

CABELEC compounds are carefully formulated products based on conductive carbon black. The type of carbon black, the addition level and the dispersion quality are key factors for achieving good conductivity – or low electrical resistivity.

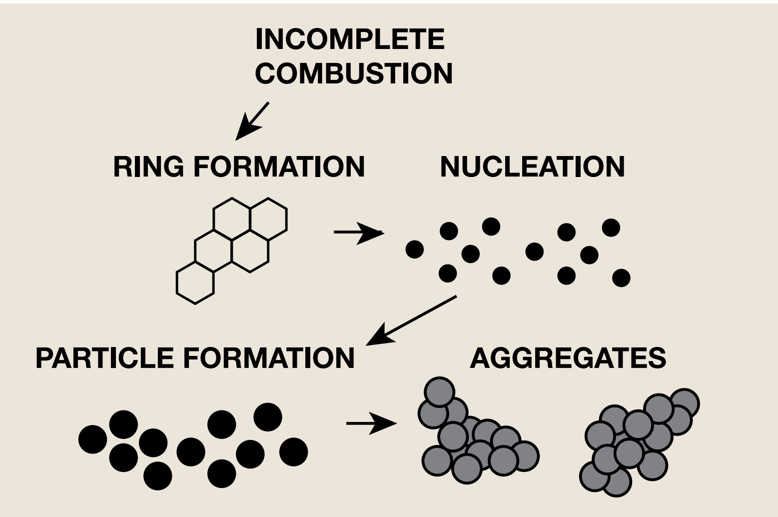
Carbon black is a particulate form of industrial carbon produced by thermal cracking or thermal decomposition of a hydrocarbon raw material. Many processes historically have been used to produce carbon black, but the most important now is the oil furnace process. It consists of atomising a heavy aromatic fraction of petroleum distillate into a preheated, closed furnace followed by cooling and collecting the formed carbon particles.

Carbon Black Oil Furnace Process



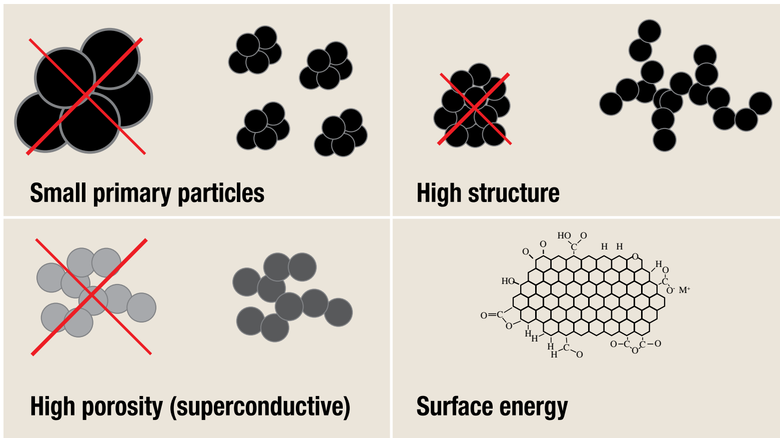
Electron microscopy inspection reveals that carbon black is composed of aggregates, which resemble fused clusters of spherical primary particles.

Carbon black oil furnace process



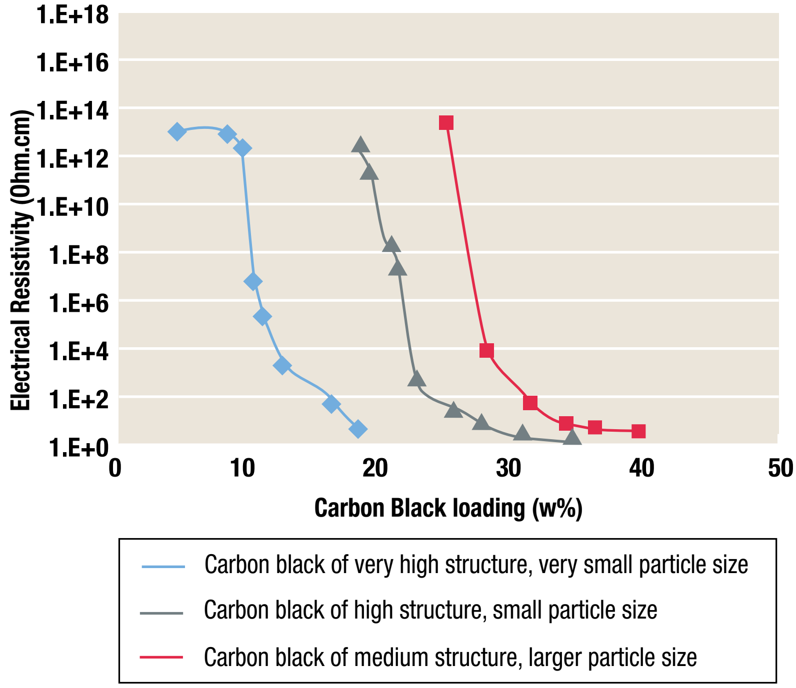
Both the aggregate size and shape, and the primary particle size, are controlling factors in determining carbon black performance.The following characteristics are key for a carbon black of good electrical conductivity:

Carbon black structure & properties



The addition level of carbon black in the polymer must be sufficient so that the carbon black particles touch, or are less than 10 nm away from each other. The relationship between the quantity of carbon black added and the electrical resistivity achieved is shown in the percolation curves below.

Examples of percolation curves



Processing
CABELEC compounds

Predrying

As the carbon black contained in the compounds is hygroscopic, CABELEC compounds should be stored in a dry place. Before processing – unless specified in the Product Data Sheet for the specific grade – the compounds need to be predried. Processing acompound having too high a moisture content will result in, for example, surface blemishes in the injection moulded part, holes in the blown film, and so on.

Processing

CABELEC compounds can usually be processed on conventional processing equipment. To ensure good electrical and mechanical properties of the material, it is strongly recommended that the compounds be processed under low shear conditions. In fact, conductive carbon black filled compounds are highly shear sensitive. Too much shear deteriorates the carbon black structure and will result in higher electrical resistivity of the manufactured item.

Processing equipment and parameters should be carefully selected so that the shear generated is kept to a minimum. For more details please refer to the specific CABELEC processing sections.

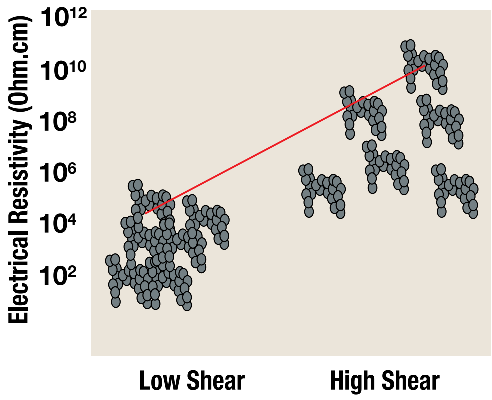
Dilution

CABELEC products provide optimum performance when used alone i.e. without dilution with non-conductive raw materials. For this reason we do not recommend dilution. In some processing techniques dilution is performed via addition of regrind. One should keep in mind the fact that the regrind is increasingly "diluted "resulting in progressively lower fractions of conductive material in the finished part. Appropriate blending and feeding procedures are required to maintain the desired resistivity levels. Rigorous testing of the electrical resistivity is also strongly recommended.

Purging

After a CABELEC production run purging of the equipment is required. Due to its high carbon black content, CABELEC can be problematic when changing to a natural or light coloured material. It is generally recommended to purge with a natural, high viscosity resin and to clean the screw and barrel mechanically.

Influence of shear on carbon black structure and electrical resistivity



Injection Moulding

Applications

Typical injection moulding applications for conductive compounds include items such as electrically conductive boxes and other types of container for the protection of electronics components against electrostatic discharge (ESD).

Where ESD protection is required for safety reasons, conductive compounds are injection moulded to produce equipment housings, fan blades, pallets, caps, valves and so on.

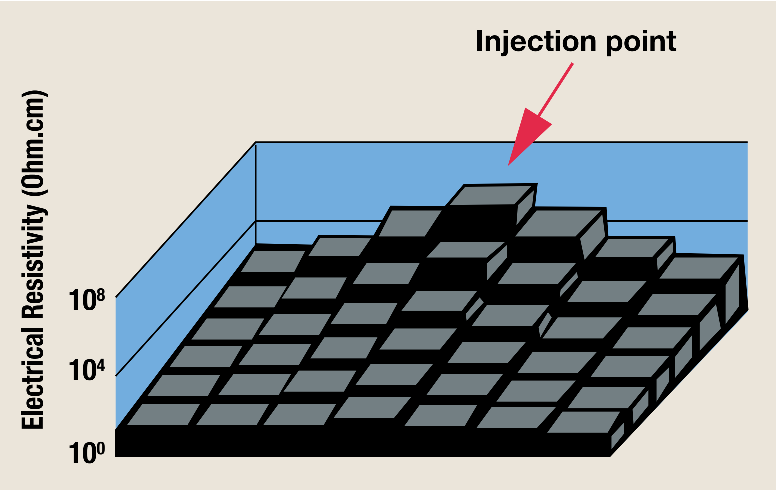
In automotive applications the main use of injection moulded CABELEC compounds is in parts for fuel systems such as fuel inlets and filler caps.

Equipment requirements for injection moulding of CABELEC compounds

CABELEC compounds can be processed on conventional injection moulding equipment although it is important to select the optimum processing conditions. To ensure good electrical and mechanical properties of the injected part, it is strongly recommended that the CABELEC compound be processed under conditions of low shear.

A general purpose screw of L/D ratio of 20-30/1 with a long feed section is recommended. The compression zone should be of low compression ratio. The nozzle can be a general purpose type of standard to large size in order to avoid any restriction of flow. Sprues can be a standard type large enough to avoid restricting material flow. Detaching mouldings from the sprue is not normally a problem but tapers may need to be increased due to the reduced shrinkage for satisfactory ejection from the mould. Due to the high viscosity of CABELEC grades compared to virgin polymers, the flow length needs to be relatively short in order to fill the mould. Therefore gates and runners should optimally be 2/3rd the wall thickness.

Inevitably there is an effect of the flow path of the molten material in the mould on the electrical resistivity of the moulded part. Electrical resistivity will be at its highest at the injection point and will decrease progressively when moving away from this point, as demonstrated in the following diagram:



Due to the generally higher stiffness of CABELEC grades, reduced forces are required for the ejector pins.

Hot runners can be used but require good tool design, extremely accurate temperature control and consistent machine settings. It is also very important that the drying guidelines are strictly followed to avoid plugging of the hot runners. Material stagnation points should be avoided by rounding the end of flow channels. Note that proto-type tooling can be a worthwhile exercise.

The shrinkage of CABELEC conductive compounds will be significantly less than that of natural polymers due to the presence of carbon black in the compound. Shrinkage values are available on the product data sheets for most CABELEC injection moulding grades.

Processing parameter	Settings versus natural polymer
Barrel temperatures	10-20°C higher
Melt temperatures	10-20°C higher
Injection pressure	Lower
Back pressure	Lower
Injection speed	Lower
Cycle time	Should be optimised when other conditions have been set and required conductivity achieved

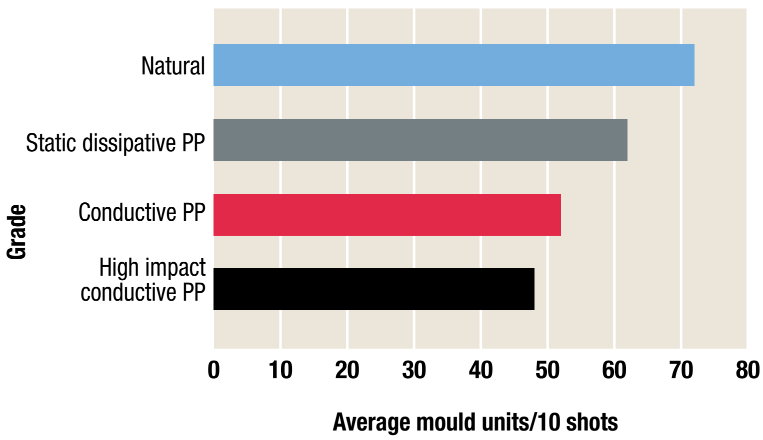
Polymer base	Recommended mould temperature (°C)
Polyacetal	60
Polycarbonate	80-100
Polyethylene	40-50
Polypropylene	30-40
Polystyrene	30

Optimum guidelines for processing of CABELEC compounds

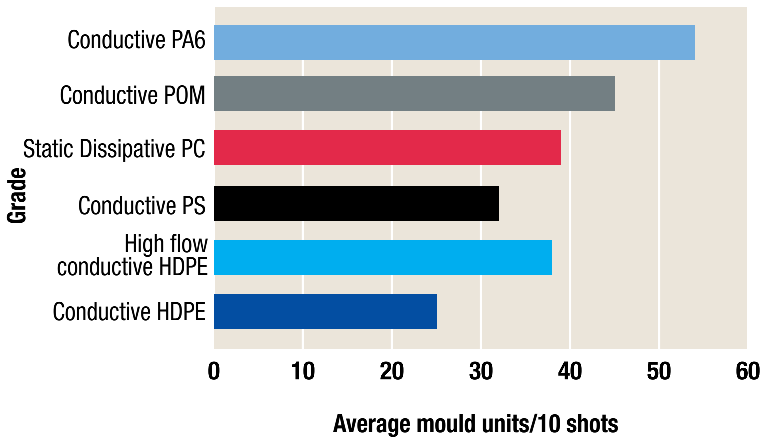
Note that cycle times will probably be similar to those for natural polymers as the higher processing temperatures together withfaster cooling characteristics will normally balance each other out.

The diagrams below compare i) the flow behaviour of 3 injection moulding CABELEC grades based on PP at their recommended melt temperature with a natural PP at its recommended melt temperature and ii) the flow behaviour of other CABELEC injection moulding grades based on different polymers:

i) Comparison of flow of PP grades versus natural PP



ii) Comparison of flow of CABELEC grades



Troubleshooting guide

Problem	Potential cause	Recommendations
Lack of conductivity	Shear too high Too much regrind Dilution too great	Increase temperature, reduce injection speed and back pressure RReduce or remove regrind Reduce or remove natural resin
Inhomogeneous surface resistivity	Non-homogeneity related to mould design	Review mould design
Cavity not filled	Viscosity too high Sprues, runners or gates too narrow Shot weight too low Melt temperature too low Mould temperature too low Injection time too short	Gradually increase melt temperature 5-10°C at a time Increase size of sprue, runners, gates Increase shot weight Increase melt temperature Increase mould temperature Increase injection time
Part sticking in mould	Low shrinkage	Reduce injection speed and injection andholding pressure
Weld lines	Flow path too short	Increase barrel temperature and mould temperature
Poor surface finish	Moisture Gas entrapment Contamination on mould surface	Dry CABELEC compound according to guidelines in product data sheet Vent mould Clean mould surface
Silver streaking	Mould temperature too low Screw speed too high Moisture Melt temperature too low	Increase mould temperature Decrease screw speed Dry CABELEC compound according to guidelines in product data sheet Increase melt temperature
Brittleness of part	Back pressure too low Screw speed too high Moisture Presence of contamination	Increase back pressure Reduce screw speed Dry CABELEC compound according to guidelines in product data sheet Check for contamination
Blisters	Moisture Screw speed too high	Dry CABELEC compound according to guidelines in product data sheet Reduce screw speed
Excessive flash	Injection pressure too high Clamp pressure too low Dirt on mould faces Mould not shutting correctly	Reduce injection pressure Increase clamp pressure Clean mould faces Check mould faces for proper fit
Gas Burns	Insufficient venting of mould Injection speed too high Screw speed too high Back pressure too high Clamp pressure too high	Ensure vents are clear of obstructions, add further vents if necessary Reduce injection speed Reduce screw speed Reduce back pressure Reduce clamp pressure, increase melt temperature ifnecessary
Oversized part	Mould temperature too low Cycle time too long Injection speed too high Injection and holding pressure too high	Increase mould temperature Reduce overall cycle time Reduce injection speed Reduce injection and holding pressure
Undersized part	Holding time too low Melt temperature too low Gate too narrow Mould temperature too high	Increase holding time Increase melt temperature Increase size of gate Decrease mould temperature
Sink marks	Holding time and pressure too low Mould temperature too high Gate too narrow Gate incorrectly positioned	Increase holding time and pressure Reduce mould temperature Increase size of gate Locate gates near heavy cross sections
Warping	Moulded in stress Uneven mould temperature Ejected part not cooled enough Ejectors not designed correctly	Raise melt temperature, reduce injection speed, relocate gate if necessary Check mould temperature Increase cooling time, reduce mould temperature Redesign ejectors
Voids	Moisture Mould temperature too low	Dry CABELEC compound according to guidelines in product data sheet Increase mould temperature

Blown Film Extrusion

Applications

- Film for packaging of electronic components
- Film for photographic applications
- Liners for big bags for explosive powders
- Packaging materials for explosive powders or other substances used in an explosive environment (as required by the ATEX norms)

Equipment requirements for blown film extrusion of CABELEC compounds

CABELEC compounds can be processed on conventional blown film extruders although it is important to select the optimum processing conditions. To ensure good electrical and mechanical properties of the film, it is strongly recommended that CABELEC compounds are processed under conditions of low shear.

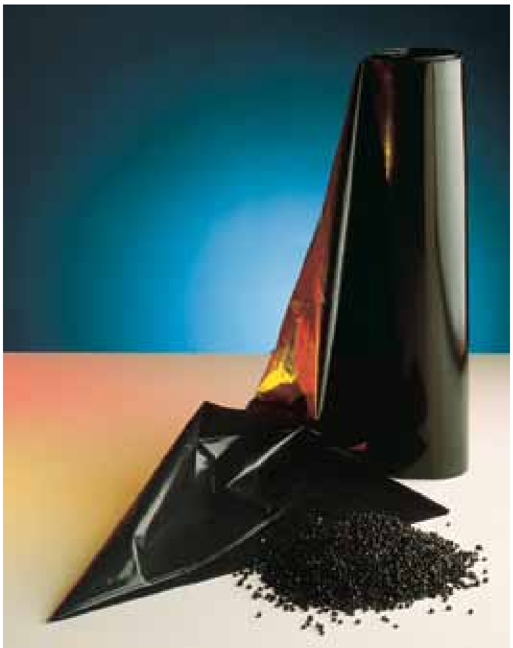
A general purpose screw of L/D ratio of 20-30/1 with a long feedsection is recommended. The compression zone should be of low compression ratio. The die head geometry should be designed toavoid or minimise any restriction of flow.

Optimum guidelines for processing of CABELEC compounds

Processing parameter	Settings versus natural polymer
Barrel temperatures	10-20°C higher
Melt temperatures	10-20°C higher
Die temperatures	20°C higher
Extrusion speed	Lower

Cooling of conductive films is normally more rapid than that of transparent, non-conductive films due to their high carbon black content which increases thermal conductivity. This factor should be taken into account when setting the process conditions.

The surface resistivity of the film is related to the film thickness: resistivity increases as the film thickness decreases.It is also important to avoid a large blow up ratio as this will increase separation of the carbon black structures thereby reducing the conductivity of the film.



Coextrusion

For conductive films, coextrusion can be used provided that a high volume resistivity is acceptable. The external conductive layers can be coextruded with a non-conductive middle layer, using cheaper polymers or recycled material which will be encapsulated in the film construction (“sandwich” structure).

Printing

Corona treatment SHOULD NOT be used on a conductive film. Nevertheless printing processes which do not require Corona treatment, for example laser printing, can be used.

Sealing

Conductive films can be sealed using standard sealing equipment. Problems may occur due to the high thermal conductivity of the CABELEC compound in which case increasing the sealing temperature can be beneficial.

Troubleshooting guide

Some potential problems that can occur with CABELEC compounds are:

Problem	Potential cause	Recommendations
Lack of conductivity	Shear too high Too much regrind Dilution too great Stretching too high Film too thin	Increase temperature, reduce speed Reduce or remove regrind Reduce or remove natural resin Reduce blow up ratio Increase film thickness
Bad sealing strength	Thermal conductivity	Increase sealing temperature and pressure
Curling of film	Inhomogeneous cooling Difference in shrinkage between the layers of a coextruded film	Reduce line speed Adapt wall thickness
Sticking of the film during winding	Film too hot during winding	Reduce speed and/or increase air cooling
Die deposit	Moisture	Dry CABELEC compound according to guidelines in product data sheet
Voids and holes	Moisture	Dry CABELEC compound according to guidelines in product data sheet

Extrusion

Applications

Conductive compounds are widely used in the electronics industry. Examples of applications are:

- Polystyrene carrier tapes
- Polystyrene thermoformed trays
- Polypropylene corrugated sheet
- Polyethylene/EVA foam

Conductive compounds are also used in industrial applications such as:

- Tubes, pipes, corrugated tubes for hazardous areas (mines, powder or chemical factories)
- Polyolefin monofilament fibres for antistatic big bags for handling of dangerous goods
- Conveyor belts

In order to comply with the ATEX norms, CABELEC conductive compounds can offer a valuable solution to producers looking for permanently conductive materials with a surface resistivity below 10^6 Ohms/sq.

Equipment requirements for extrusion of CABELEC compounds

CABELEC compounds can be processed on conventional extrusion equipment although it is important to select the optimum processing conditions. To ensure good electrical and mechanical properties of the extruded part, it is strongly recommended that the CABELEC compound be processed under conditions of low shear.

A general purpose screw of L/D ratio of 20-30/1 with a long feed section is recommended. The compression zone should be of low compression ratio. The die can be a general purpose type of standard to large size in order to avoid any restriction of flow.

Extruders with mixing elements, restrictions in the barrel, high compression ratios, melt pumps or tight screen packs should be avoided. Low screw speeds are recommended. It is also important to avoid beads on calender rolls, to optimise nip roll temperature sand to match extrusion and haul-off speeds.

Optimum guidelines for processing of CABELEC compounds

Processing parameter	Settings versus natural polymer
Barrel temperatures	10-20°C higher
Melt temperatures	10-20°C higher
Die temperatures	20°C higher
Extrusion speed	Lower

Coextrusion

For conductive sheets, coextrusion can be used provided that a high volume resistivity is acceptable. The external conductive layers can be coextruded with a non-conductive middle layer, using cheaper polymers or recycled material which will be encapsulated in the film construction (“sandwich” structure).

Dies

When extruding conductive sheets, it is sometimes necessary to have a temperature differential between the external and internal part of the die: the external part being hotter. This is to compensate for the longer flow path of the external part of the sheet compared to the internal part. However a temperature gradient in the sheet can cause additional shear negatively affecting the conductivity.

Stretching

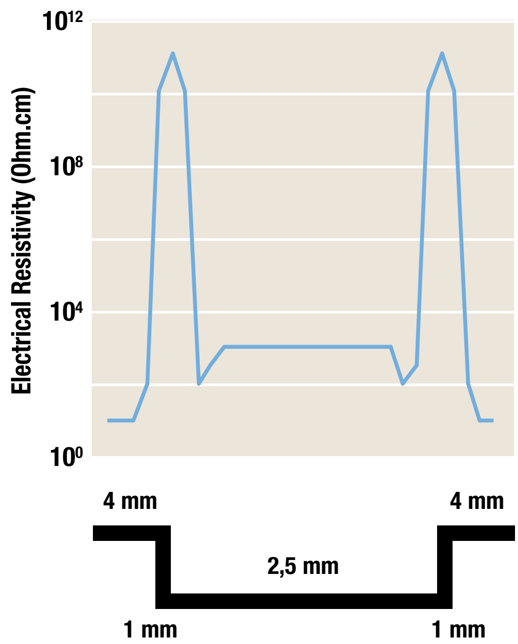
After extrusion, stretching should be very limited because it increases the distance between the carbon black structures thereby negatively affecting the conductivity. Ideally the die gap should be the same as the sheet thickness. This is particularly important when extruding monofilaments.

Calenders

If the extruded sheet has to pass between two calenders (nips) for cooling, it is recommended that the upper roll is set at a temperature 6-10° C above the lower roll. Another very important factor is to minimise the rotating bead between the calender rolls. High shear is generated in this bead which sometimes dramatically deteriorates the surface resistivity of the material. If the bead is absolutely required to guarantee the thickness distribution, it should be kept to a minimum.

Thermoforming

Special care needs to be taken during the thermoforming process due to the varying degrees of shear to which different parts of the sheet are subjected. Conductivity can be lost in vertical sections due to separation of the carbon black structures. In other words, the surface resistivity will be highest in the thinnest parts of the thermoformed article as illustrated below:



Troubleshooting guide

Some potential problems that can occur with CABELEC compounds are:

Problem	Potential cause	Recommendations
Lack of conductivity	Shear too high	Increase temperature, reduce speed
	Too much regrind	Reduce or remove regrind
	Dilution too great	Reduce or remove natural resin
	Material too stretched	Avoid stretching after extrusion Avoid nip beadsEnsure homogeneous cooling by adjusting temperatures of calenders and die
Inhomogeneous surface resistivity	Non-homogeneity related to thermoforming process	Increase thickness, review thermoforming resistivitythermoforming processdesign avoiding excessive stretching
Poor surface finish	Moisture	Dry CABELEC compound according to guidelines in product data sheet
Die deposit	Moisture	Dry CABELEC compound according to guidelines in product data sheet
Voids	Moisture	Dry CABELEC compound according to guidelines in product data sheet

Blow Moulding

Applications

CABELEC conductive compounds are used in a variety of blow moulding applications ranging from large containers such as industrial bulk containers (IBC's), drums and jerry-cans to technical parts such as conductive automotive filler pipes. Many containers made of CABELEC compounds designed for the transportation of dangerous goods have successfully passed the UN test procedures and are listed as BAM approved packaging. When compared with natural polyethylene, conductive compounds show a higher sensitivity to shear, a faster cooling rate due to better thermal conductivity and a slightly higher viscosity. The most important parameters for the processing of CABELEC grades are summarised in the guidelines below.

Equipment requirements for blow mouldingof CABELEC compounds

CABELEC can be processed on most conventional continuous extrusion as well as accumulator head equipment. Screws with grooved feed zones and L/D ratios between 20 and 30 are recommended. Despite the shear sensitivity of conductive materials, usual shear- and mixing elements of HDPE screws are suitable provided a minimum of precautions are taken for the process conditions. With appropriate grade selection, coextruded parts and containers can be successfully produced from CABELEC products.

Conventional moulds are generally suitable for the manufacture of CABELEC parts. General guidelines for natural polyolefins are still valid.

Processing parameters

The main process parameters that should be considered are listed below with their corresponding guidelines/explanations :

Processing parameters	Comments/recommendations
Temperatures	Melt temperatures : typical range : 200-240°C Die lip temperature : typical range : 210-240°C A too low die lip temperature can affect resisitivity even at higher melt temperatures. It can also generate variation in conductivity along the circumference of the parison
Piston or Ram speed	On accu-head lines the ram speed should be kept as low as possible due to the high shear rates generated during parison formation
Screw speed	Conventional screw speed levels for natural polymers can be used
Mould closing speed	As for natural HDPE the appropriate balance needs to be found to achieve good welding quality. An excessive speed (or too late transition point to reduced speed) can lead to an inappropriate weld geometry
Parison cooling/mould cooling	CABELEC compounds exhibit a far higher thermal conductivity than natural polymers. As a result parison cooling is faster. This leads to shorter cooling times but also needs to be taken into consideration for the welding line quality
Melt strength	Due to the carbon black network CABELEC products are characterised by high melt strength levels which help to reach a tight thickness distribution profile
Mould temperatures	As for natural polyethylene low mould tempertaures are preferable to minimise cycle time (typical cooling water temperatures : 10-25°C)

Troubleshooting guide

Problem	Potential cause	Recommendations
Rough surface	Melt temperature too low Die temperature too low Ram speed too high	Increase melt and die temperatures Reduce ram speed
Flow marks/surface defects	Purge effect due to high viscosity of CABELEC	Complete purge of the equipment
Bubbles	Air entrapment, excessive moisture level	Vent the equipment, pre-dry material
Weld seam is too weak	Melt temperature is too low Extrusion/ram speed too low Mould closing speed inappropriate	Adjust melt temperatures Increase ram speed Adjust mould closing speed and change-over limits
Uneven appearance on mould surface	Insufficient or non homogeneous venting	Improve venting
Surface resistivity too high	Die lip temperature too low Melt temperature too low Excessive shear	Increase (significantly) die lip and melt temperature Reduce ram/piston speed
Uneven resistivity levels	Uneven parison resistivity Uneven stretching/blow up ratios	Increase head/die temperatures Verify thickness distributio

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