FLEXIBLE POLYMERS _ WIRE & CABLE GRADES FOR MEDIUM/HIGH VOLTAGE POWER CABLES

Lucofin® 1400HN, Lucofin® 1400MN, Lucofin® 1494H, Lucofin® 1494, Lucofin® 7410 HFFR, Lucofin® 7440 HFFR

LUCOBIT
THERMOPLASTIC POLYOLEFINS

OPPORTUNITIES FOR LUCOBIT PRODUCTS IN MEDIUM/HIGH VOLTAGE POWER CABLES

GENERAL

Medium/high voltage power cables play an essential part in our infrastructure for the distribution of electrical energy in rural and especially in urban areas. Figure 1 shows the function of power cables within the electric grid.

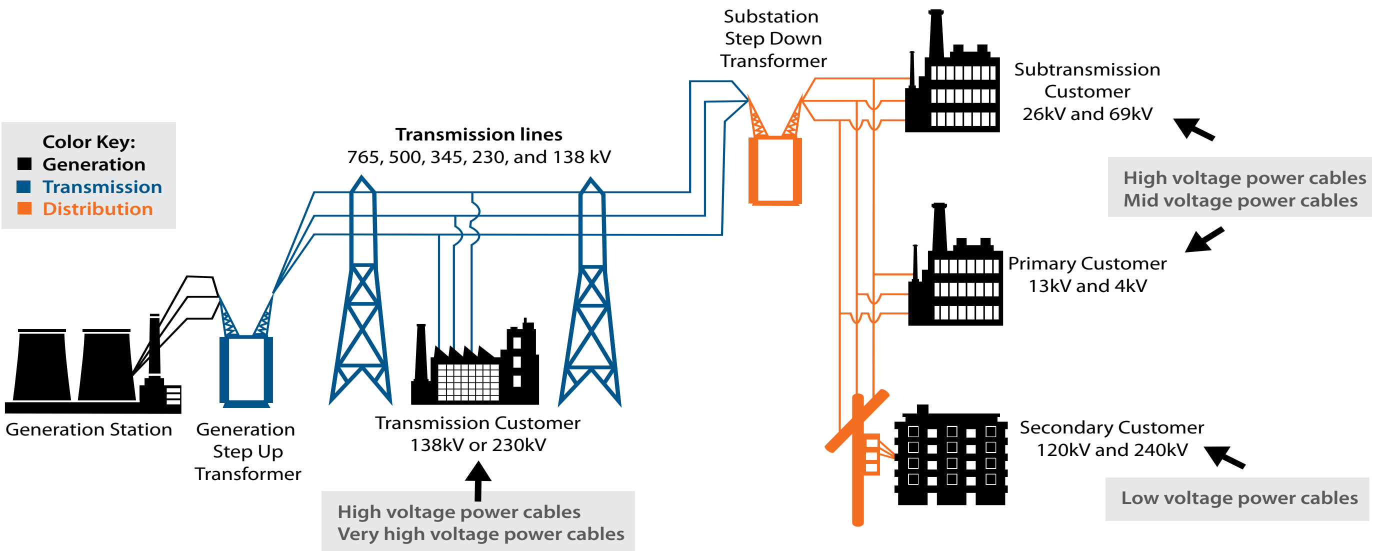


Figure 1: Positioning of power cables within the electric grid

The transmissions lines from the generation station to an intermediate substation are made up of high and very high voltage power cables. From there high voltage and mid voltage power cables distribute the electrical energy to subtransmission and primary customers. Finally, the secondary customer is supplied with electrical energy via low voltage power cables.

Polymeric medium/high voltage power cables first appeared in the early 1950s and soon overtook the oil-impregnated paper and fluid filled cables. Nowadyas, the replacement of overhead lines as well as the rapid development of renewables energies are important global growth factors for polymeric medium/high voltage power cables (see box1).

REPLACEMENT OF OVERHEAD LINES

- Overall ownership of cost
- Environmental aspects
- Substainability and maintenance
- Burden of land (blocking of area around overhead lines due to negative impact of electromagnetic radiation towards humans)
- Denmark planning to substitute all overhead lines by power csbles no later than 2040

REPLACEMENT OF OIL-IMPREGNATED PAPER AND FLUID FILLED CABLES

- Cost efficiency
- Development of supersmooth semicons
- Development of tree retardant insulation

UPCOMING OF RENEWABLES ENERGIES

- On-shore/off-shore wind power
- Photovoltaics
- Geothermal energy

Box 1: Global growth factors for polymeric medium/high voltage power cables

LUCOBIT MATERIALS FIT FOR USE IN MEDIUM/HIGH VOLTAGE POWER CABLES

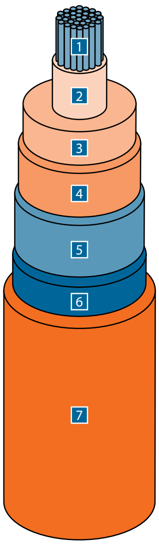
LUCOBIT AG, headquartered in Wesseling, Germany and former part of BASF, offers the following materials fit for use in medium/high voltage power cables:

- two ethylene butyl acrylate copolymers (EBA):
  - Lucofin® 1400HN
  - Lucofin® 1400MN
- two maleic anhydride grafted (MAH) ethylene butyl acrylate copolymers (EBA):
  - Lucofin® 1494H
  - Lucofin® 1494
- two ready made HFFR compounds based on ethylene butyl acrylate copolymers (EBA):
  - Lucofin® 7410 HFFR
  - Lucofin® 7440 HFFR

Lucofin® 1400HN, Lucofin® 1400MN, Lucofin® 1494H and Lucofin® 1494 contain 16 % - 17 % butyl acrylate and are designed to be part of a formulation. On top of that, Lucofin® 1494H and Lucofin® 1494 contain a high amount of grafted maleic anhydride making them efficient coupling agents. Due to their low MFI Lucofin® 1400HN and Lucofin® 1494H are more suited for lowly filled compounds, whereas 1400MN and Lucofin® 1494 with their high MFI are used mainly in highly filled compounds.

With Lucofin® 7410 HFFR and Lucofin® 7440 HFFR LUCOBIT supplies ready made Halogen Free Flame Retardant (HFFR) compounds with precipitated aluminium tri hydrate (ATH) in case of Lucofin® 7410 HFFR or with precipitated magnesium di hydrate (MDH) in case of Lucofin® 7410 HFFR as the mineral flame retardant.

A typical design of a medium/high voltage power cable showing typical applications (marked orange) for Lucofin grades is depicted in figure 2. Table 1 summarizes in more detail recipe recommendations for the various layers of the cable as well as the major points imparted by using Lucofin grades.



1. Copper conductor

2. Conductor shield: internal semi conductive compound based on Lucofin 1400MN

3. Insulation XLDPE-XLLDPE compound requiring dosage of Lucofin 1400HN with water treeing test being a major challenge

4. Conductor shield: external semi conductive compound based on Lucofin 1400MN

5. Conducting bond

6. Layer of copper

7. HFFR sheathing made of Lucofin 7410 HFFR / Lucofin 7440 HFFR or other HFFR grades based on Lucofin 1400HN / Lucofin 1400MN / Lucofin 1494 / Lucofin 1494H

Figure 2: Design of a medium/high voltage power cable showing applications (orange) for Lucofin grades

Table 1: Opportunities for Lucofin grades in medium/high voltage power cables

INTERNAL SEMICONDUCTOR Smooth surface | Thermally stable | Excellent carbon black dispersion | No premature peroxide reaction | Low viscosity | Good adhesion to conductor and insulation interfaces **55 % - 60 % Lucofin 1400MN** 35 % - 40 % Carbon black 1 % - 3 % Peroxide 1 % - 2 % Additives	EXTERNAL SEMICONDUCTOR (FULLY BONDED) Smooth surface | Thermally stable | Excellent carbon black dispersion | No premature peroxide reaction | Low viscosity | Good adhesion to insulation interfaces **55 % - 60 % Lucofin 1400MN** 35 % - 40 % Carbon black 1 % - 3 % Peroxide 1 % - 2 % Additives
INSULATION LAYER Water tree retardant | Improved environmental stress cracking | Extremely Clean reaw materials | No premature peroxide reaction **10 % - 20 % Lucofin 1400HN** 80 % - 90 % LDPE 1 % - 3 % Peroxide 1 % - 2 % Additives	JACKETING (REGULAR) Chemical resistant | Mechanically robust | Flexible at low temperatures **5 % - 20 % Lucofin 1400HN** 80 % - 95% LDPE/LLDPE/MDPE/HDPE 1 % - 2 % Additives JACKETING (HFFR) Flame retardant | Chemical resistant | Mechanically robust | Flexible at low temperatures **Lucofin 7410 HFFR** **Lucofin 7440 HFFR** *or* **15 % - 25 % Lucofin 1400MN / Lucofin 1400HN** **4 % - 6 % Lucofin 1494** 5 % - 15 % POE (polyolefin elastomer) / POP (polyolefin plastomer) 60 % - 65 % ATH / MDH 1 % - 2 % Additives

LUCOFIN 1400MN AS A MASTERBATCH CARRIER FOR SEMICONDUCTIVE COMPOUNDS

The number and the size of protrusions are key for the quality of a semiconductive compound. Figure 3 shows a typical device for the detection of protrusions on a tape based on the semiconductive compound in question. The monochromatic light coming from a laser is diffracted at the irregularities of the tape followed by a photometric analysis.

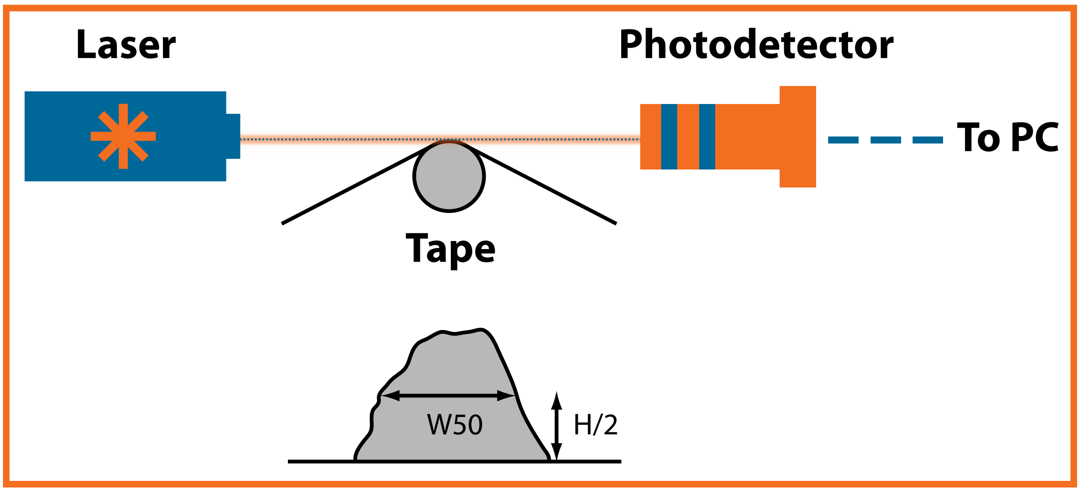


Figure 3: Experimental set-up for the analysis of protrusions in a semiconductive compound

The use of ethylene butyl acrylate copolymer (EBA) in combination with the right type of carbon black, typically acetylene carbon black, results in a supersmooth insulation and conductor shield with significant less protrusions as shown in figure 4. Due to the lower electrical stress employed the requirements for an insulation shield are less severe than those for a conductor shield.

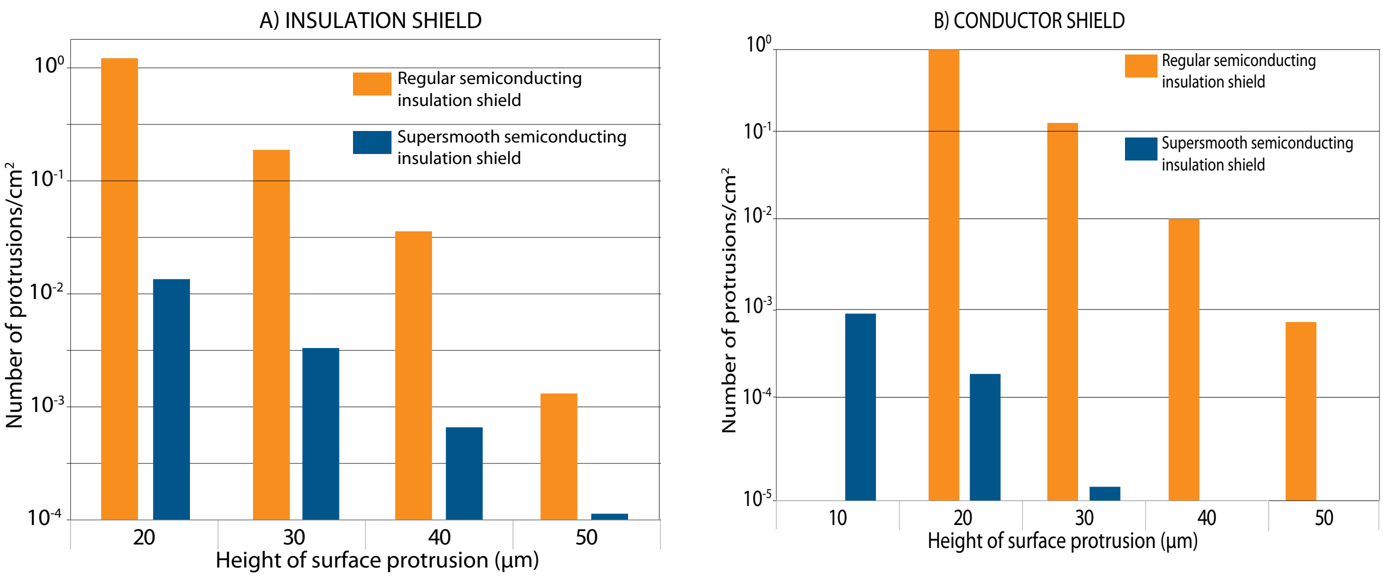


Figure 4*: Number of protrusions vs. their height for a regular and supersmooth semiconducting a) insulation shield and b) conductor shield

*data taken from: Power and Communication Cables, R. Bartnikas, K. D. Srivastava, A John Wiley & Sons, (1999), 90

LUCOFIN 1400HN AS A WATER TREE RETARDANT FOR INSULATION COMPOUNDS

Over time inside the insulation of a medium/high voltage power cable so-called water trees may evolve. These lead to a reduction of electrical strength and may eventually cause the electrical break-down of a cable. Therefore, water tree retardant (TR) insulation compounds are commonly used today. At a dosage of roughly 20 % in a XLPE compound ethylene butyl acrylate copolymer (EBA) is a powerful water tree retardant due to its polarity passing a variety of different accelerated electrical aging tests and therefore contributing to the longevity of a cable. Figure 5 shows that the water tree length -being an indicator for the expected failure rate of a cable- is at optimum using a TR-insulation as well as a supersmooth semicon.

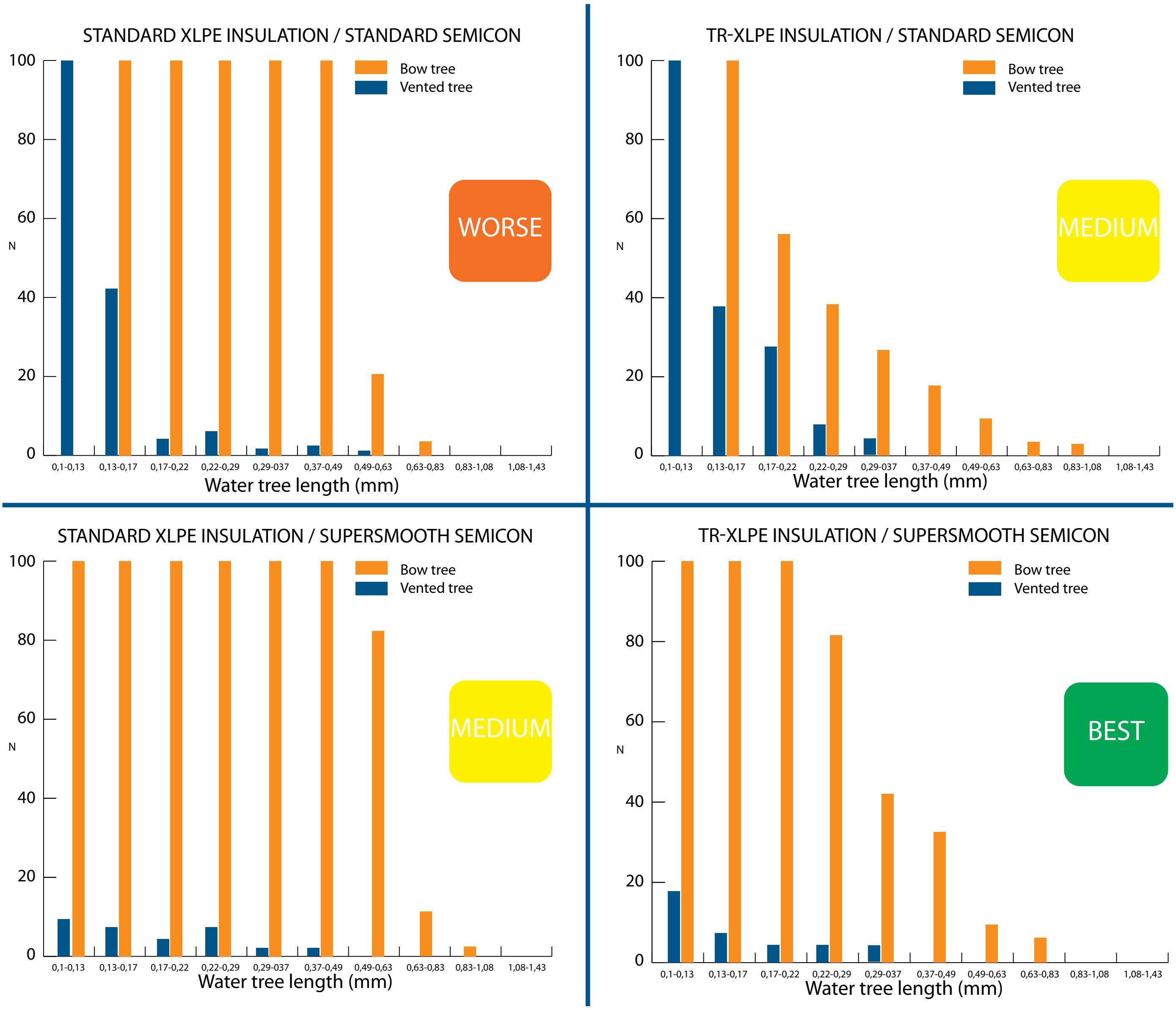


Figure 5*: Effect of type of insulation and semicon on length, type and number of water trees in a 30 kV mid voltage power cable, TR = tree retardant

*data taken from: Power and Communication Cables, R. Bartnikas, K. D. Srivastava, A John Wiley & Sons, (1999), 149

LUCOFIN® 7410 HFFR AND LUCOFIN® 7440 HFFR FOR A FLAME RETARDANT JACKETING MATERIAL

In comparison with traditional HFFR grades based on ethylene vinyl acetate (EVA) / ATH ethylene butyl acrylate copolymer (EBA) based Lucofin 7410 HFFR and Lucofin 7440 HFFR have the following advantages:

1. Very low water absorption and only little drop of electrical and mechanical properties after water storage: suitable for cables in wet areas

2. Excellent low temperatures flexibility: suitable for cables in cold areas

3. Good ageing properties: suitable for cables in hot areas

4. Increased production output for Lucofin 7440 HFFR: suitable for high line speed cables

5. Superior processing stability avoiding issues like surging during cable extrusion and resulting in very few fluctuations of layer thickness therefore offering the potential for using less material

6. Exceptional environmental stress cracking resistance (ESCR): making them fit for use in desert conditions and other ESC critical applications

Figure 6, 7, 8 and table 2 show exemplary the low water absorption, the elongation at break before and after water storage, the superiour aging resistance as well as the environmental stress cracking resistance of Lucofin® 7410 HFFR and Lucofin® 7440 HFFR as compared to EVA based compounds. On the next page some further characteristica of ethylene butyl acrylate copolymer (EBA) based Lucofin® 7410 HFFR and Lucofin® 7440 HFFR are illustrated.

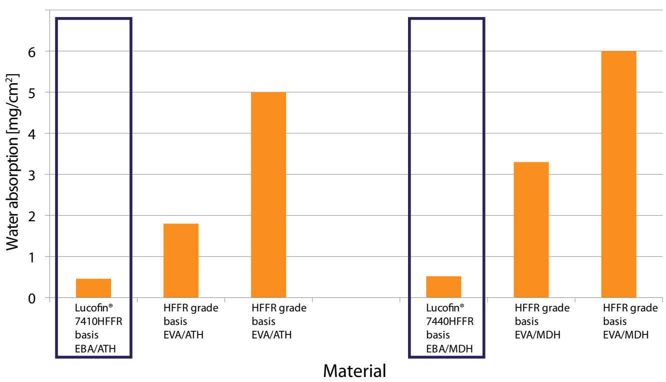


Figure 6: Water absorption of various HFFR grades

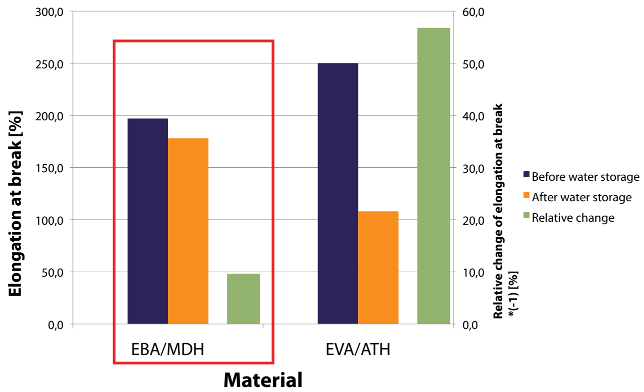


Figure 7: Elongation at break of some HFFR compounds before/after water storage and relative change

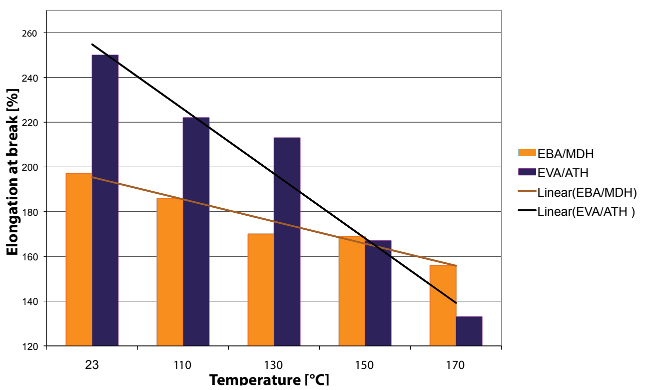


Figure 8: Elongation at break of HFFR compounds based on EBA/MDH and EVA/ATH as a function of storage temperature

Table 2: Environmental stress cracking resistance of various HFFR compounds

MATERIAL	TEST
Lucofin 7410 HFFR EBA/ATH compound	pass
Lucofin 7440 HFFR EBA/MDH compound	pass
"Standard 1 EVA/ATH compound 1	fail

1000 h at 50 °C subjected to Igepal CO-630 (Ethoxylated nonylphenol) in a stressed mode: cracks: yes/no measured at hot pressed samples

LUCOFIN® 1400MN / LUCOFIN® 1400HN AS A POLYMER CARRIER AND LUCOFIN® 1494 AS A COUPLING AGENT IN A HFFR FORMULATION FOR A FLAME RETARDANT JACKETING MATERIAL

Cable converters with self compounding facilities have the option to produce their own HFFR compounds based on ethylene butyl acrylate copolymer (EBA). In case of a proper formulation design –table 1 gives here some guidance- the advantages are similar to those as enumerated on the previous page.

Further advantages of ethylene butyl acrylate copolymer (EBA) based compounds are excellent low temperatures properties making them fit for „siberain" and other low temperature conditions. The scientific rational is that Polybutylacrylate has one of the lowest glass transition temperatures (Tg) of any polar ethylene copolymer with -56 °C (see figure 9). Therefore, EBA based HFFR compounds –Lucofin 7410HFFR and Lucofin 7440HFFR- maintain their flexibility at lower temperatures as compared to EVA based HFFR compounds (see Dynamical Mechanical analysis in figure 10).

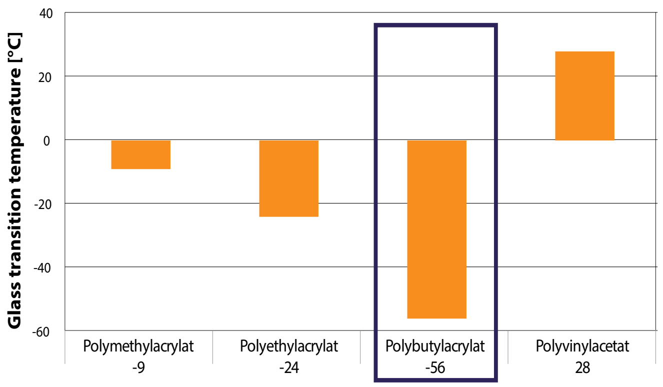


Figure 9: Glass transition temperature of some polar ethylene copolymers

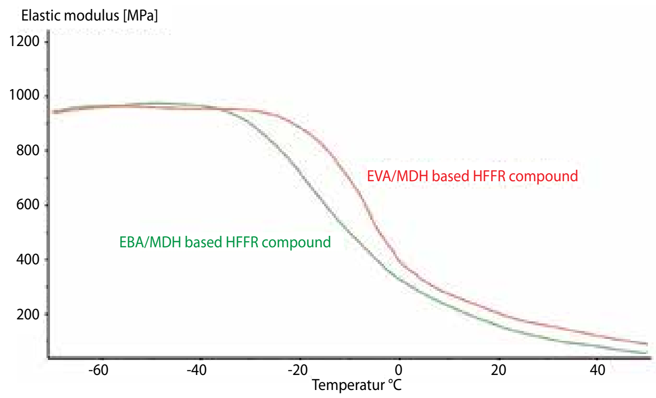


Figure 10: Dynamical Mechanical analysis (DMA) of HFFR compounds based on EVA/MDH and EBA/MDH

These findings translate into practice oriented tests. Figure 11 shows that the cold elongation of EBA based compounds reaches the requested value of > 20 % even at -50 °C, whereas EVA based compounds fail this requirement below -15 °C. In a smilar way, EBA based compounds pass the cold impact test at – 50 °C. Opposed to this, EVA based compounds fail this important test at -50 °C (see table 3).

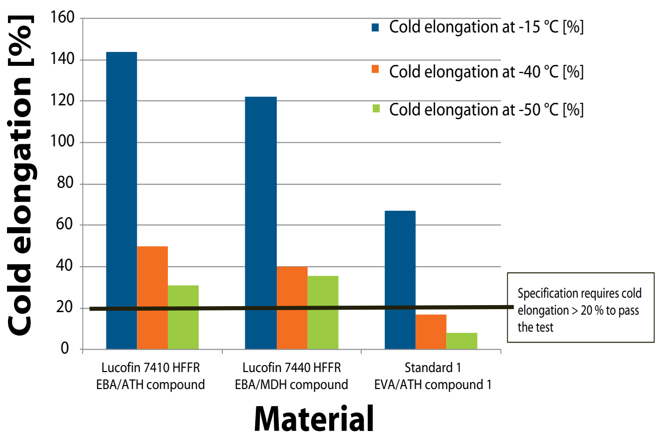
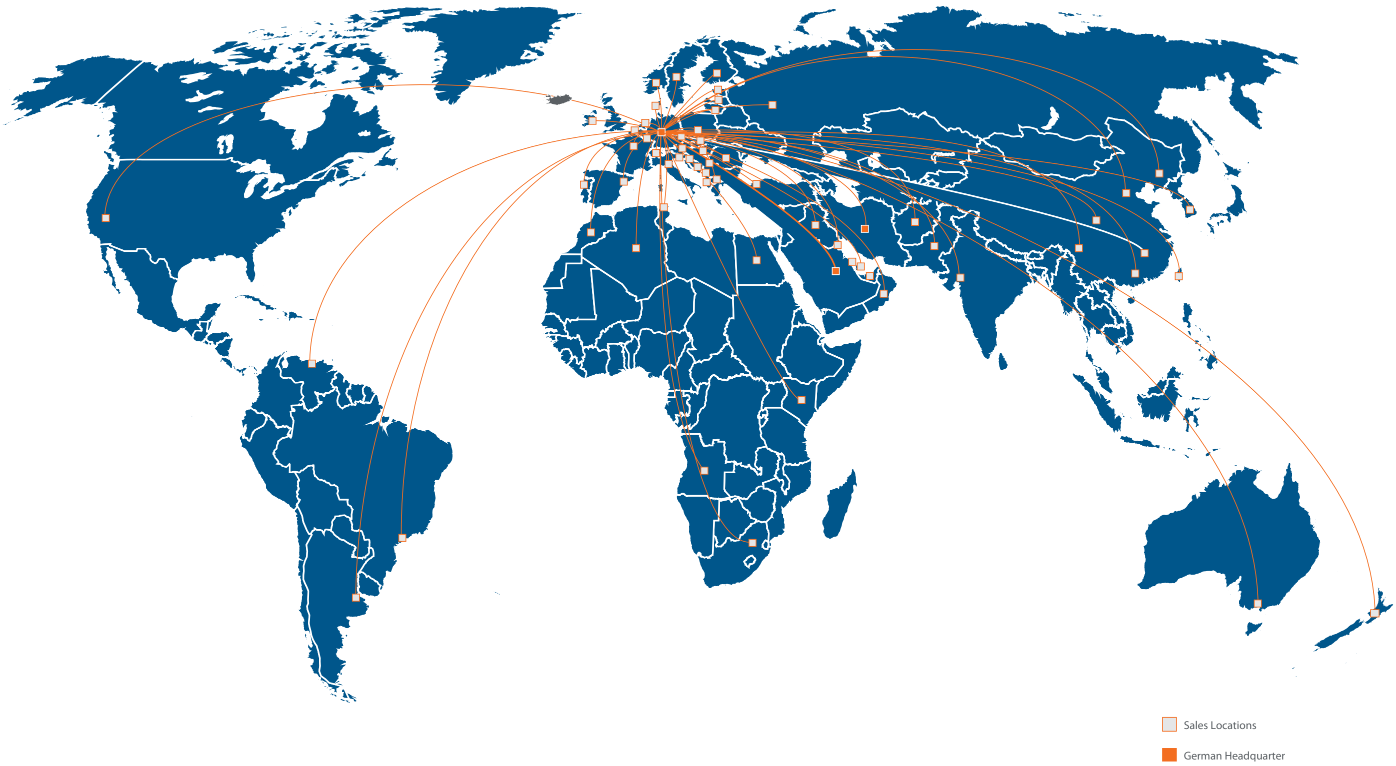


Figure 11: Cold elongation at -15 °C, -40 °C and -50 °C for various HFFR compounds

Table 3: Cold impact at -50 °C for various HFFR compounds

MATERIAL	COLD IMPACT AT -50 °C
Lucofin 7410 HFFR EBA/ATH compound	pass
Lucofin 7440 HFFR EBA/MDH compound	pass
Standard 1 EVA/ATH compound 1	fail

LOCATIONS



Note

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