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IRRADIATION TECHNOLOGIES AND COMPOUNDS FOR CABLES CROSS-LINKING – DEVELOPMENTS FOR FLAT AND HEAT-TRACE CABLES

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ABSTRACT

Irradiation technology is used since the seventies to cross-link sheath and insulation of cables. Generally, the main expected improvement is temperature and creep resistance (hot set test), but secondary improvements like increased chemical resistance to fluids like oils, greases, and higher resistance to abrasion are also researched. Irradiation technologies and facilities are presented hereinafter, followed by the suitable materials for that technology and some scopes of applications of cross-linked cables.

KEYWORDS

Irradiation, cross-linking, temperature resistance, creep resistance, hot set test.

INTRODUCTION

2 types of radiations can be use for cross-linking:

- Accelerated Electrons:
  - They are generated by an accelerator, creating an electron beam (EB technology).
  - The electron beam scans the cables filing off under it (fig. 1).
  - Penetration and treated depth are correlated to the energy of the accelerated electrons and of the type of accelerator.
- Gamma Rays:
  - It consists of photons emitted by a radioactive source (Cobalt 60). It is an electromagnetic radiation.
  - Complete bobbins are disposed in totes (containers) and file off around the Cobalt source

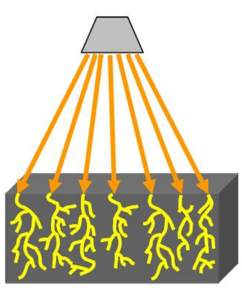

Figure 1: Principle of EB process

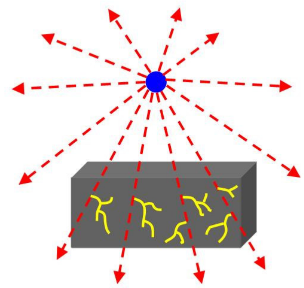

Figure 2: Principle of Gamma process

IRRADIATION TECHNOLOGY

Electron beam (EB) is the most well-known and widespread technology for cross-linking cables, but gamma rays can be more practice for specific products whose potentialities are increasing: flat cables and of heat-trace cables.

Irradiation is used since the seventies to cross-link sheath and insulation of cables.

Principle of radiation cross-linkikng reaction and process

The first effect of irradiation is to create the **ionization** of the material: a great amount of free radicals are created along the polymer chain, according to the following reactions [1]:

Molecule AB decomposes into an electron and a cation:

$$AB \rightarrow AB^{+} + e^{-} \qquad [1]$$

Cation AB^{+} is generally unstable and it decomposes into a free radical $B^{\bullet}$:

$$AB^{+} \rightarrow A^{+} + B^{\bullet} \qquad [2]$$

At the end, ionization results into the creation of a free radical $B^{\bullet}$:

$$AB \rightarrow A^{+} + B^{\bullet} + e^{-} \qquad [3]$$

$B^{\bullet}$ is able to induce different chemical reactions based a free radical process: cutting of polymer chains, polyaddition, polymerization …

Generally, on a hydrocarbon polymer chain, A = H (hydrogen), B = C (carbon).

On a second step, irradiation cross-linking is based on the reactions between free radicals. They react between each other to give new covalent bondings between the polymer chains, and create a three dimensionnal network in the polymer.

Transfer of energy and dose

- In the 2 cases of radiations, ionization consists in the transfer of energy from electrons or photons to the matter.
- Energy of the incident radiation is expressed in mega electron volts (MeV).
- The amount of energy received by the matter is called **DOSE** and is expressed in grays or kilograys: 1 kGy = 0.1 Mrad = 1 k Joule / kg
- There is no risk of inducing radioactivity because the incident energy of the accelerated electrons and of the photons can only break electronic interactions in the electronic orbit, without disturbing the nucleus (no formation of isotopes).

Irradiation facilities

In the 2 cases of rays, the scheme of an irradiator is the following one:

- The source of radiations (electron accelerator or cobalt 60 source) is located in a bunker shielded with lead or concrete.
- A conveyor passes through the bunker :
  - ♦ A winding system is used for extruded products in case of EB.
  - ♦ Also for EB, rollers are used for parcels.
  - ♦ Container carriers (or totes) are used for Gamma irradiators.
- There are distinguished storage areas before and after the conveying system.

EB technology is the most well-known and widespread for cross-linking cables. Its characteristics are:

- The depth of treatment is correlated to the energy of the accelerated electrons, and thus to the energy of the accelerator (fig. 3).
- The dose of treatment is controlled by the power of the accelerator and by the speed of the conveying system.
- It is possible to use several accelerators at the same time, in different directions, in order to optimize the treatment of the insulation around the conductor.
- The EB treatment is never on extrusion lines because of their different speeds.

Gamma technology has the advantage to make possible to treat complete bobbins without winding them (figure 4), because of the higher penetrating ability of the gamma radiations (electromagnetic wave). The bobbins can be treated into totes that can receive bobbins of 40 cm-diameter and up to 1.70 m high. But, in order to keep a homogeneous treatment, the presence of metal acting as a screen stopping the radiations should be limited. And, this is especially the case of flat cables and of heat-trace cables.

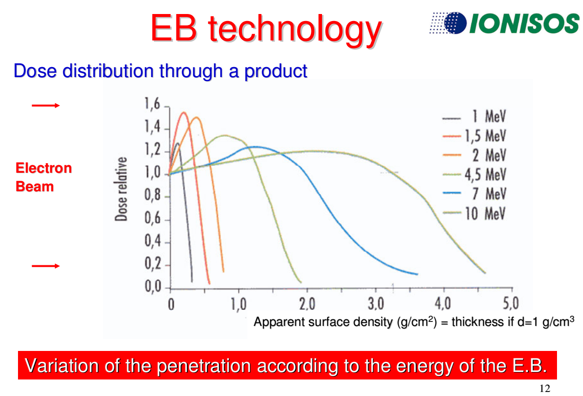

Figure 3: Energy guidelines for choosing the EB characteristics tailored to the characteristics of the thickness of the sheath or the insulation of the cables, in relation with the density of the material.

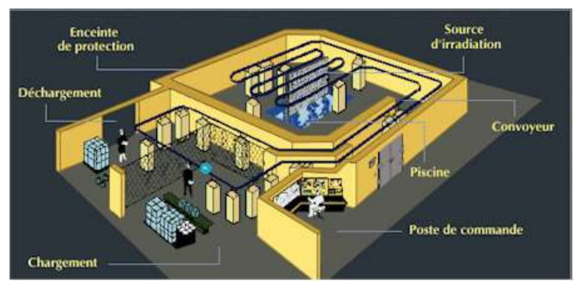

Figure 4: Principle of a gamma plant processing by totes (photograph from Ionisos).

MATERIALS FOR RADIATION CROSS-LINKING

Polyolefins are the most well-known materials for cross-linking, and irradiation technology is often in competition with chemical technologies like the silane one in the case of polyethylene.

But irradiation shows very interesting advantages, like:

- The formulation can be easily designed by the extruding manufacturer, and its extrusion is easier compared to the silane technology in the case of which the silane additives increase the viscosity.
- Irradiation cross-linking is a quick-acting process, and consequently, the cross-linking rate is more controlled.
- It is not necessary to invest a lot owing to the fact that the irradiation step can be sub-contracted.

Most of all polyolefins' providers proposes radiation cross-linkable PE (table 1).

PROVIDER	GRADE NAME
BASELL	LUPOLEN 4261 A Q416
BOREALIS	HE 2590, HE 2595
BP SOLVAY POLYETHYLENE	ELTEX K46

Table 1: 3 examples of radiation cross-linkable HDPE.

Other materials, especially elastomers and thermoplastic

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elastomers (TPE) can only be cross-linked by irradiation or are more competitive in case of irradiation, because of the low kinetics of reaction related to chemical solutions: soft PVC, Polychloroprene, EPDM, HNBR / EVM, TPV, TPU … Some ready-for-use compounds are available on the market (table 2).

MATERIAL	PROVIDER	GRADE NAME
PP/EPDM based TPE	AES / EXXON MOBIL	DYTRON XL 7300
TPU	ELASTOGRAN	ELASTOLLAN LP 9218, LP 9219

Table 2: PP/EPDM – based TPE and TPU radiation cross-linkable grades.

In case of PP/EPDM based TPE (DYTRON XL 7300), the effect of radiation cross-linking is to make it filling the hot set test specification: till a radiation dose of 33 kGy (fig. 5).

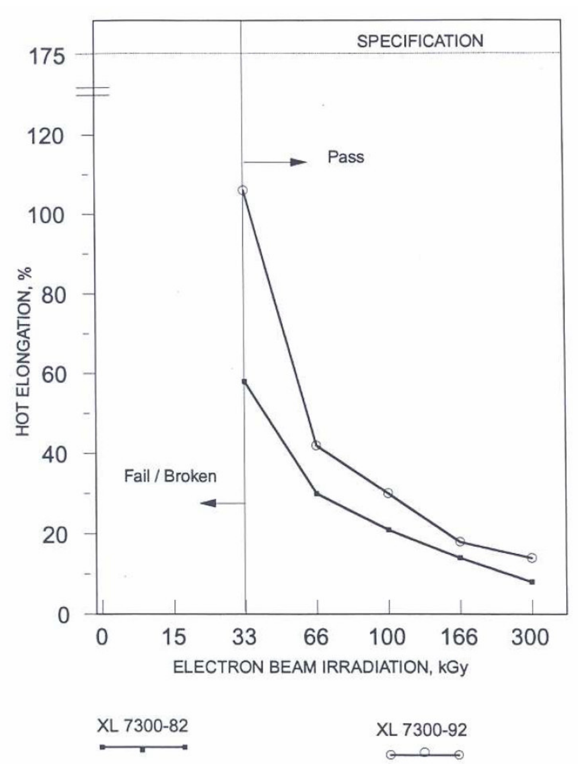

Figure 5: Hot-set test of XL 7300 versus EB irradiation [3].

Generally, the main expected improvement is temperature (table 3) and creep resistance (hot set test), but secondary improvements like increased chemical resistance (fig. 6) to fluids like oils, greases, and higher resistance to abrasion are also researched.

Dose (kGy)	0	100	300
HDT (°C)	58	67	75

Table 3: Heat distortion temperature HDT (load: 0.45 MPa) of radiation cross-linked HDPE versus the dose (source: Ionisos).

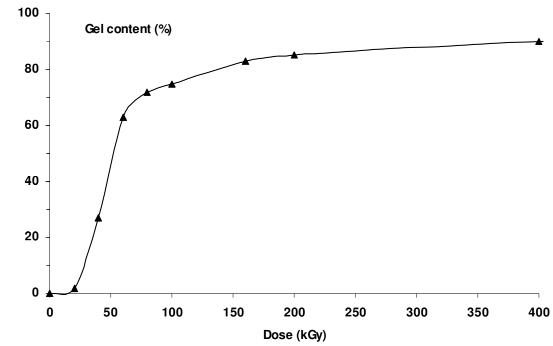

Figure 6: Gel content of polyethylene in xylene versus the dose [2].

APPLICATIONS AND ADVANTAGES AND DRAWBACKS OF EACH TECHNOLOGY

Automotive uses a great volume of radiation cross-linked cables, essentially because of their higher dimensional stability at high temperature between 125 and 200°C (depending on the material), and because of their flame resistance (no incandescent drop).

Heat-trace cables is a lower market, but with some high technology uses: heating cables for comfort and security in cars, and for security in aeronautic.

The table 4 presents different criterions for choosing between different possibilities of radiation treatment: investing in one's own irradiation facility ("integration") or using a service company ("sub-contracting")?

	EB	
	Integration	**Sub-contracting**
Advantages	Self made treatment.	An irradiation centre has generally a range of different EB accelerators of different energies tailored to each type of sheath or insulation.
Drawbacks	Minimum 200.000 km / year for making the facility profitable.	Payment of an external service.

	Gamma	
	Integration	**Sub-contracting**
Advantages	Self made treatment.	The service company is responsible of all the specifications and expectations related to a nuclear plant.
Drawbacks	• Maintenance and regulations of a nuclear plant. • The cobalt source capacity (activity) is divided by 2 every 5 years.	Payment of an external service.

Table 4: Various criterions for choosing the radiation technology.

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[1]: A. Chapiro, 1962, *Radiation Chemistry of Polymeric Systems*.., Interscience Publishers, New York, 712 p.

[2]: A.J. Swallow, 1960, *Radiation Chemistry of Organic Compounds*, Pergamon Press, p. 159

[3]: *Dytron XL Thermoplastic Rubber – Flexible Halogen-free Flame Retardant TPEs*, brochure from AES.