PLEXCHEM Technologies

Chemistry for Good

LED-UV RADIATION TECHNOLOGY

About Us

Plexchem Technologies positions itself as a technology innovator, creating exciting processes, systems, and products for use in the infrastructure industry. These include products for the insulation and coating of cables, specially designed materials for the piping industry (for which we won an international award in 1998), processing equipment, a software support system and testing equipment for quality control and assessment of cable quality.

Plexchem Technologies started out as an XLPE compound producer in 1988 supplying compounds to customers in many nations in Africa, Europe, N, and S America, Australia and Asia.

As a pioneering supplier, we realized that our simple infusion process is well suited for cable companies to make compounds for their own use as well as for others. Moreover, the XLPE market was expanding rapidly and many cable companies expanded the production of XLPE compounds to the point where it was economical for these companies to consider self- compounding.

In 2006, the decision was made by **Plexchem Technologies** to focus our efforts into becoming a technology provider rather than a compound supplier to our many cable customers. These companies were already familiar with our compounds and would now have the chance to enjoy real savings, with respect to the cost of rentals, packaging, manpower, deliveries, and profit. Other realizable benefits include the supply of fresh compounds devoid of concern for shelf life, enhanced technical competence and the ability to fully integrate the cable company's manufacturing processes.

Our approach is simple. We provide everything from the technological know-how, equipment and the chemical concentrate that would allow the cable companies to make their own compounds with the least amount of effort and cost. In addition, **Plexchem Technologies** will continuously assist the cable company in troubleshooting and in the introduction of new products and processes.

Plexchem Technologies remains engaged in every aspect of cable technology. From the development of an environmental friendly anti-vermin (*anti termite and anti rodents*) masterbatch, including a special paint to coat cables that are already in service, to the technology offered to cable companies to manufacture their own peroxide, halogen-free flame retardant (HFFR) and crosslinked HFFR compounds. In addition, **Plexchem Technologies** have introduced processes and systems for the extrusion and testing of cables. Our under one-hour aging equipment (AAA) and the skin extrusion system have all been introduced to assist cable companies to manufacture and test cables expeditiously and inexpensively.

Most recently **Plexchem Technologies** introduced three new products and services. We have developed a low-cost Lead Extrusion Line in collaboration with Honta (an established cable equipment supplier) that is almost half the cost of the nearest competitor. To assist companies in the integration and coordination of the various cable manufacturing processes, the company has introduced Cablesoft. The most recent and exciting product innovation is **UV crosslinking** to which information related to this process can be found in the contents of this brochure.

The company looks forward to working with you.

Introduction

Ultraviolet (UV) crosslinking of Polyethylene which uses ultraviolet light (UV) as a radiation source for crosslinking has been around since the early 60s. However, the equipment available in those early years, severely hindered the commercialization of this process, because it produced inconsistent products that had inconsistent crosslinking at various depth due to the poor UV penetration, unsatisfactory homogeneity of crosslink chains, health and safety concerns (ozone emission is of concern) and a slow production process which was dominated by frequent stoppages. As a result, research and development in high energy irradiation processes dominated the industry.

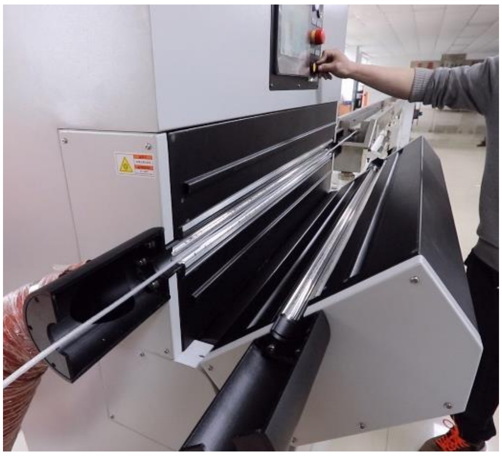
In the late 1990s and early 2000s, the development and introduction of new LED UV lamps which produced less heat and hence less volatiles which, in the past, tended to darken the UV source making the lamps ineffectual after only short production runs. Further, the lower initial cost, the exceptionally long life of these LED lamps as compared to the previous mercury lamps and the low energy consumption, made this process both chemically and economically viable. With the development of better photo-initiators and low-cost formulations, Ultraviolet crosslinking has seen a resurgence. Today's UV crosslinking system can be optimized to attain high-efficiency production processes with short irradiation times, manufacturing products up to 4mm wall thickness, with high and consistent gel content.

These days, various PE compounds (of diverse MFIs, Densities, and most fillers) can be UV crosslinked, producing a host of different products with improved properties, from crosslinked cables, pipes, tapes, and other everyday objects.

Ultraviolet Crosslinking Equipment

The Ultraviolet crosslinking equipment (fig 1) consists of a touch screen control system which ensures that the wavelength and intensity of ultraviolet irradiation remain constant. The heart of the UV crosslinking equipment consists of a round chamber that is surrounded by LED ultraviolet lamps. These lamps produced the UV necessary for the initiation of the crosslinking process and are specially designed to reflect and focus the UV light source on to the cable that is to be crosslinked. The LED lamp has high energy efficiency, narrow wave band with (5nm half power width), with little or no Ozone generation, less infrared red radiation (heat) and long expectancy (up to 30,000 hrs.). The radiation power can be set from 0 to 100% giving the system the flexibility in deciding on the process conditions. The cost of replacement is about USD1,500 multiplied by the number of units that you have (typically 8 or 14 units).

Figure 1: The Addmix UV chamber



The chamber can be pneumatically split open at the center to allow for simple and effortless set up of the whole cable extruding process (fig 2), including cleaning (simply using a glass cleaning detergent and soft tissue) of the lenses after extrusion.

Figure 2: The chamber can be pneumatically opened for easy excess

Attached to the UV Crosslinking Equipment are two other units that are an integral part of the whole process. A decontamination chamber is used to eliminate any undesirable volatiles that is produced by the migration of chemicals out of the extrudate during UV crosslinking and the removal of any volatiles that would obscure the UV radiation from reaching the product.

Another auxiliary unit is the cooling system, necessary in assuring that the temperature within the chamber remains cool (below 25°C) which is essential in ensuring that the electronics system is functioning properly. Fig 3 shows a schematic of the UV crosslink chamber and the auxiliaries.

Figure 3: shows the Addmix UV chamber together with the auxiliary units

Production Process

The production process uses the same equipment that is utilized to produce PVC, PE or moisture cured XLPE cables. The UV crosslinking chamber is placed between the cable extruder and the first water cooling trough (fig 4 & 5). The compound enters the UV irradiation chamber directly after extrusion, in the molten state. At this temperature, PE is almost transparent to visible and ultraviolet light which makes it possible to crosslink all the way into the interior of the insulation. The cable resides in the UV chamber for 0.5 to 2 sec depending on the insulation thickness and any additives that reduce the transparency of the insulation (e.g. colors except black, minerals and additives). It is important to ensure that the cable remains taut so that the cable remains firmly at the center of the chamber.

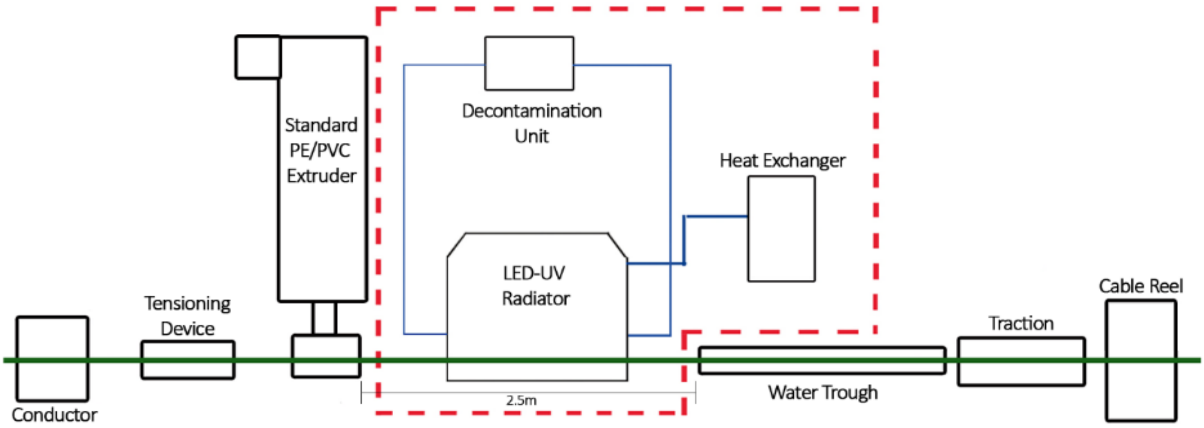
Figure 4 Cable entering the UV chamber

Figure 5 Cable exiting the UV chamber

The cable is crosslinked within the UV chamber and exits at the other end where other secondary processes can be administered (e.g. coextrusion of carbon black skin/semicon) or directly into the water trough for cooling.

The mechanical and thermal test can be conducted on the cable immediately upon cooling.

Installation Schematics



Advantages of UV crosslinking

I. ***Low equipment cost:*** There is no need for expensive CV tubes (peroxide systems) or Electron beam equipment (electron beam) or even curing rooms. No need for costly constructions or repositioning of the existing equipment. The UV crosslinking chamber is located just after the existing cable extruder, occupying the space where the cooling water trough is situated (thus, necessitating the moving of the water trough 2.5 meters away from the extruder die). The small space that it occupies can be adapted to fit any cable extruding system. The UV crosslinking chamber is less than 5% the cost of a CV or E-beam system and costs almost nothing to install.

II. ***Low energy consumption:*** The system consumes a maximum of 20KW of electricity excluding the power consumption of the existing cable extruder. No need for power guzzling CV tubes or high voltage field within a high vacuum acceleration tube or even curing chambers. Unlike silane XLPE cables, which requires post-extrusion curing (steam at 90̊C), which sometimes run 6 hrs. long, UV crosslink cables are crosslinked as soon as it leaves the chamber.

III. ***Ease of processing****:* With silane compounds (Siloplast, Siloxan and Monosil systems) the base polymer plays an important part in the outcome of the finished cable. Using LLDPE will give orange skin insulation (melt fracture) and poor shrinkage. Using LDPE results in the poor hot set and requires a longer curing time. Both polymers will result in pre-crosslinking. However, with UV radiation crosslinking low MFI LLDPE can be used which gives excellent hot set, low shrinkage values, and smooth insulation surface.

IV. ***No peroxides:*** This crosslink system does not contain any peroxides in the formulation. Peroxides cause pre-crosslinking of the extrudate and will contaminate the screw and die. Further, while peroxides are dependent on temperature for storage and processing, UV polymerizable compounds are not and are stable, even at room temperature, in the absence of UV light.

V. **C*ompounds have a long shelf life:*** Silane XLPE has a shelf life of the compound of at most 1 year before it becomes crosslinked by the moisture that can penetrate the sealed bags (most likely made using expensive Aluminum foil). This renders the compound useless. UV crosslinking compounds are not grafted (reacted) and as such do not undergo pre-crosslinking.

VI. ***Satisfactory production speed:*** The speed indicated in table 1, depends on the wall thickness and any additives or fillers that affects the transparency of the extrudate.

Cross Section Area of conductor: Mm^2	**Insulation Nominal Thickness: mm**	**Line speed M/min**
2.5-16	0.7	70-120
25-35	0.9	80-100
50	1.0	50-80
70-95	1.1	40-80
120	1.2	35-70
185	1.6	35-65
300	1.8	35-45
400	2.0	35-45
630	2.4	25-35

Table 1 estimate production speeds

VII. ***Testing can be done immediately after cooling:*** The crosslinking process is completed during extrusion thus preliminary tests can be conducted and results obtained within half an hour after the commencement of production. Information obtained from actual production cable samples allows the operators to adjust the operating condition more definitely. So often, many kilometers of silane derived XLPE cables are discarded because testing can only be conducted hours after production and curing had been completed, too late for changes to be made if processing conditions are not perfectly ideal.

VIII. ***Meeting all requirements for XLPE crosslink cables:*** Table 2 gives the result of 1 KV cable samples. Testing results have produced excellent results especially the very high gel content which is difficult to achieve using silane XLPE crosslink cables.

Test	Results	Units	Requirement
Mechanical properties			
Tensile strength	21.7	N/mm2	12.5
Elongation at break	520	%	250
Thermal Properties			
Aging (135°C & 7Days)			
(i) Tensile retention	93	%	25<
(ii) Elongation retention	87	%	25<
Hot set test (200 °C, 15 min)	53	%	175<
Permanent elongation	+5	%	15<
Shrinkage (130°C 1hr)	1.5	%	4<
Chemical Test			
Gel	78	%	>75
Electrical test			
Volume resistivity at 90°C	3.2 X E16	Ω cm	
Withstand voltage test	Pass	2.4kV, 5hr	

Table 2 Typical test results obtained using 16mm2 crosslinked insulation.

IX. ***Post-production activities can be performed almost immediately:*** One of the major advantages in using UV crosslinking compounds is that the extruded cables are ready for post-production activities such as twisting, armoring and jacketing, almost immediately after extrusion.

X. ***Ability to manufacture medium voltage cables:*** Medium voltage cables can be made using clean UV cross-linkable compounds. The extruded cable is sealed from environmental contaminants using special adaptors which allows the coextruded semicon/insulation to be UV crosslinked and then coated with a thermoplastic layer of conductive black. Like the initial coextruded semicon/insulation, the skin extruder is linked to the UV crosslinking chamber by a continuous adaptor thus, excluding any foreign material to be deposited on the insulation/semicon layer. Results of 10KV cables are shown in table 4.

XI. ***Colored and HFFR compounds can be crosslinked:*** UV crosslink is now available with color masterbatch (including the low concentration of black masterbatch) and special HFFR compounds are able to be UV crosslinked.

XII. **L*ow-cost UV crosslink compounds:*** The cost is about the same as silane XLPE compounds but less than both peroxide and E beam compounds. Most likely the UV compounds will be supplied by a domestic supplier. Even self-compounding by cable producers is a possibility.

High Draw Down ratios are possible: Even as high as 3 to 1 draw down ratios the shrinkage remains at below 2% (fig 6). High Draw Down, especially for sector shaped cables, will allow the insulation to snugly follow the sector shape boundary of the cable.

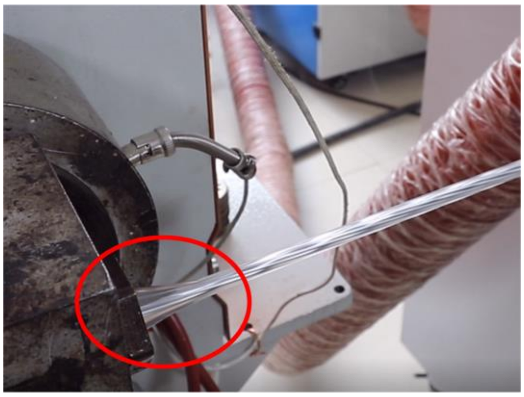


Fig 6 showing a drawdown of 2.5 to 1. The resulting cable has a shrinkage value of 1%.

XIII. ***Less material usage:*** With a high Draw Down, less material (about 3% for small cables to 5% for larger cables) is deposited within the grooves of the cable formed by the twisting of many strands of the circular conductor. This is especially more noticeable if pressure extrusion is used. Fig 7 shows the amount of additional material that is used as a result of the grooves.

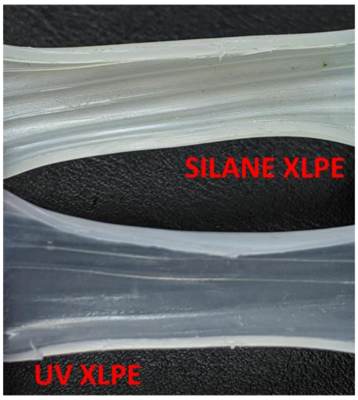


Fig 7 The twisting of strands of the conductor will result in grooves being formed on the conductor surface. Therefore, more material is being deposited in the inner surface of the silane XLPE cable as seen in the picture.

XIV. ***nontoxic chemicals:*** The chemicals used in the compounding are nontoxic and are RoHS and Reach compliant.

XV. **L*ess waste:*** There is no need for discarding cables that are made at the beginning and at the end of the extrusion process because of nonstandard operating conditions. In a CV line, this waste could amount to 200-500 meters of cables which cannot be recycled. In the case of UV crosslinking (and for that matter, Silane and E beam) the extrusion of useable UV crosslinked cables can commence almost immediately after the first compound is purged from the extruder.

Crosslinking mechanism

The system employs a photo-initiator and a photo co-initiator as the free radical generator. On absorption of the desired UV, the hydro acetophenone molecule will be cleaved into two free radicals as shown in fig 5.

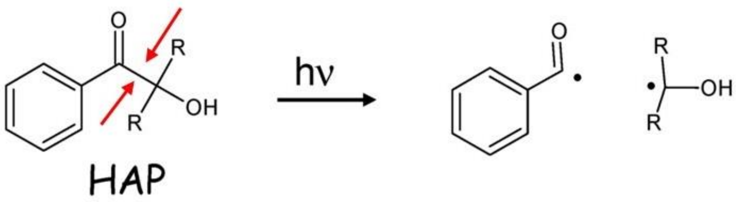


fig 5: shows the cleavage of the hydro acetophenone into two free radicals that are ready for crosslinking

The formulation uses another type of photo-initiator, which on the absorption of UV of a specific wavelength will extract hydrogen from the co-initiator and in the process splitting the bond pair as shown in fig 6. Hydro acetophenone has the hydroxy group which also acts as a co-initiator.

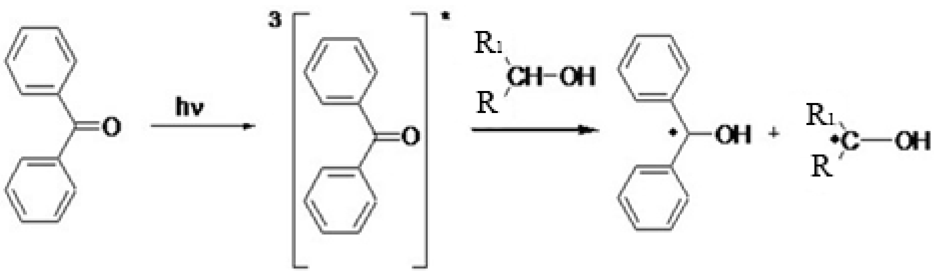


fig 6. The radicalization of benzophenone.

Once the free radicals are generated, the polymerization of PE polymers commences with the abstraction of Hydrogen from the Polymer, thus forming the polymeric free radical. These polymeric free radicals will follow the same chain propagation and termination steps found in other free radical processes.

Cost comparison between Silane moisture cured and UV irradiated crosslinking

The main drawback for water curing compound is the time and cost of curing, especially for thick insulations. Typical curing times vs thickness for moisture cured systems are given in table 3.

Thickness of insulation (mm)	0.7-1.2	1.2-2	2-2.2	2.4
Ave. cure time in steam (hr)	4	5	7	8
No of drums in curing chamber*	24	18	15	8
Length of cable/drum (KM)	3	3	2.5	2
Cost of steam curing cable (US $/KM)	0.4	0.65	1.3	3.6

table 3: the average number of drums that can fit into a 20 ft container. A steam generator requires 2X24 KW of electricity. Electricity cost is US 15cts/KWh

The UV tubes consume 16KWH of electricity (the cost of electricity @ US 15 cents/ KWh). The cost is almost identical for thin insulation but the cost significantly widens for larger insulation thickness. this is shown in table 5.

The thickness of insulation (mm)	0.7	1.2	2.0	2.4
Ave speed of line (m/min)	100	70	40	30
KM produced in 1 hr.	6.0	4.0	2.4	1.8
Cost of running UV (US $/KM)	0.4	0.6	1.0	1.3

table 4: the cost of producing 1 KM of cable strictly running the UV

<u>other significant benefits</u>

a) ease of processing as the compound is thermoplastic and only crosslinks in the UV chamber.

b) ease of cleaning as there are no pre-crosslinking substances in the extruder (material is still thermoplastic while in the extruder).

c) the cables are fully crosslinked after passing through the UV chamber and test can be conducted to determine the quality of the cable and verify if further adjustments need to be made to the processing conditions. How often have cables been trashed because of the failure to meet the desired quality standards?

e) secondary processes or post-production activities can be performed almost immediately.

<u>cost of compound</u>

The current cost of the compound is under USD1600/mt with PE at USD1050/mt. Obviously, the cost of the compound will increase in tandem with the increases in the price of PE. This compares quite favorably with the current prices of silane and peroxide compounds.

A video demonstration showing the processing of a cable using UV crosslinking is available on Plexchem's website.

The Plexchem Family

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