WHITE PAPER

Revised 2023

Electron-beam crosslinking

Salient Features

- Operating temperature -185˚C to +155˚C
- Flame retardant
- Halogen free
- Very low smoke
- Non-Toxic
- Weather resistant
- High abrasion resistance
- Ozone & UV resistant
- High tracking resistance
- Easily strippable & highly flexible
- Hot pressure resistant
- Soldering iron resistant
- High current carrying capacity
- Very high short circuit resistant
- Enhanced installed life for 50+ years
- Does not melt/drip under fire condition
- Good for high-rise buildings, crowded places and modern data centers
- Super thin wall
- Robotic X Y Z flexibility
- High dynamic cut through resistant
- High tear resistant
- High elasticity
- Sub zero temperature bending & high impact resistant
- Very high circuit integrity
- Outstanding fluid and alkaline resistance - Resistant to variety of reactive chemicals, oil, grease and solvents
- Resistance to corona effect
- HL3 fire protection
- And more

Electron Beam Accelerator for the Wires and Cables Industry: Enhancing Performance and Quality Reliability

1. Introduction

Electron beam accelerators have emerged as a transformative technology in the cable industry, offering a range of applications that enhance performance and quality. These accelerators utilize high-energy electron beams to modify materials, providing numerous advantages over traditional methods.

Insulation cross-linking is a key application where electron beams induce cross-linking in polymer-based insulation/sheath materials. This process improves the mechanical and thermal properties of the insulation, resulting in cables that are more resistant to heat, chemicals, and physical stress.

Sterilization of cables is another significant use of electron beam accelerators. The high-energy electron beams effectively eliminate microorganisms, ensuring the safety and hygiene of cables. This method provides a fast, efficient, and chemical-free solution for sterilizing cables without compromising their performance.

Material modification is a versatile application enabled by electron beam accelerators. These beams allow precise adjustments to the molecular structure of cables, enhancing their mechanical, thermal, weathering, oil resistant and electrical properties to meet specific requirements.

By harnessing electron beam accelerators, the cable industry benefits from improved insulation/sheath properties, enhanced sterilization capabilities, tailored material modifications, and precise printing. These advancements contribute to the production of high-performance, durable, and safe cables that meet the evolving needs of various industries with salient features as mentioned in the cover page.

2. History

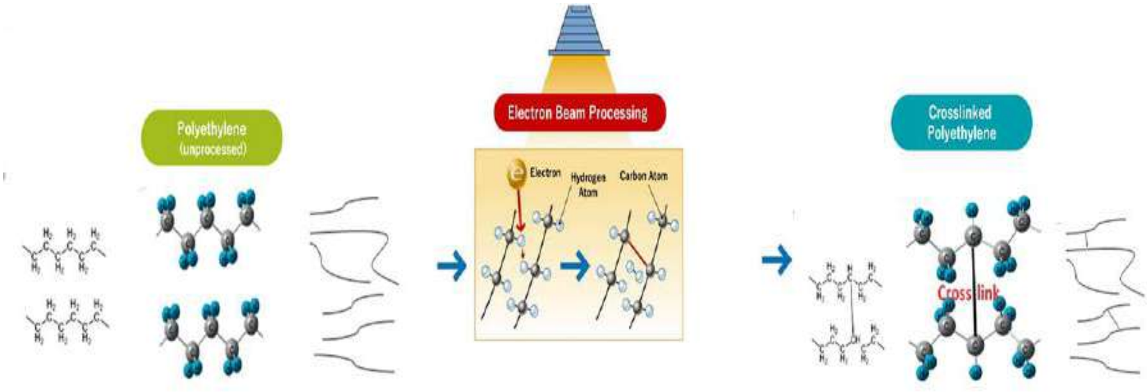
The history of electron beam accelerators in the cable industry can be traced back to the mid-20th century. With the increasing demand for high-performance cables, researchers and engineers began exploring the potential of electron beam technology for enhancing cable properties. In the 1960s, electron beam accelerators were first employed for insulation cross-linking, revolutionizing cable manufacturing processes. The ability of electron beams to induce cross-linking in polymer-based insulation materials improved the mechanical and thermal properties of cables, making them more durable and resistant to various environmental factors. Over the years, advancements in electron beam accelerator technology, such as improved beam control and higher energy levels, have further enhanced the capabilities and efficiency of cross-linking processes in the cable industry. Today, electron beam accelerators are a vital component of cable manufacturing, enabling precise modifications and ensuring the production of high-quality, high-performance cables for a wide range of applications.

3. Polymer Material

Electron beam accelerators offer a versatile solution for cable manufacturing, allowing the use of various polymer materials that can be modified to meet specific requirements. Polyethylene (PE) is commonly employed as an insulation material, and electron beam accelerators facilitate cross-linking to enhance its mechanical and thermal properties. Similarly, polyvinyl chloride (PVC) is widely utilized for cable jackets, and electron beam irradiation improves its resistance to electrical, thermal, and chemical properties. Other polymers, such as ethylene propylene rubber (EPR), ethylene propylene diene monomer (EPDM), cross-linked polyethylene (XLPE) and cross-linked polyolefin (XLPO) can also undergo modification using electron beams to enhance their performance as cable insulation or jacketing materials. Additionally, specialty polymers like fluoropolymers (e.g., ETFE, PVDF) and other elastomers can be cross-linked or modified using electron beam technology to provide specific properties such as high temperature resistance or flexibility. The ability to modify various polymer materials using electron beam accelerators allows cable manufacturers to tailor the properties of cables to meet the demands of different applications, ensuring high-performance and reliable cable solutions.

4. Effect of electron beam cross linking

Electron beam bombardment, or electron beam irradiation, is used to induce crosslinking in polymers. Under the influence of radiation (accelerated electrons or gamma radiation), the C-H bonds are broken. Further, the C-bonds of macromolecules are stitched together, forming a kind of grid of cross-links. As a result, positive changes in the physical properties of the polymer occur. Including the polymer becomes stronger. The atoms of the released hydrogen interact with each other. As a result, hydrogen molecules H2 and methane CH4 are formed. The gas output is about 0.4 litres per 1 kg of polymer. Therefore, the density of the polymer varies slightly, but not significantly. The resulting gases should diffuse onto the surface of the wire. This process continues even after irradiation.



The radiation crosslinking process is far superior with assured 100% homogeneity than the steam/moisture polymerization process, which has poor homogeneity in cross linking around 60% and problem of post curing when the cables are installed in hot/humid environment because it has a catalyst added while processing whereas in EBXL process no catalyst is required. Electron beam cross linking has many advantages: productivity is much higher, electron irradiation ensures uniform crosslinking over the entire thickness of the wire insulation, whereas steam/moisture crosslinking is effective only in surface layers with a small thickness of wire insulation that too about 60% of cross-linking homogeneity. With a large insulation thickness, the unevenness increases. To raise the uniformity, it is required to provide exposure in hot water (90 to 100 degrees) for many hours on metal drums where the same when used often contaminates the insulation layer and the whole process is in dirty water with unknown metal particles and a primitive way of processing.

2.5 MeV are generated in an electron beam accelerator, as in a conventional transformer. Initially, 50 Hz is converted to 400 Hz to reduce the size of the accelerator, then the alternating voltage inside the accelerator is rectified and becomes constant. A constant voltage is applied to the accelerator tube in which the electrons are accelerated. The energy of accelerated electrons is maintained with an accuracy of +/-3%. Since the energy is always constant, the electrons penetrate the polymer to the same depth, which provides better irradiation quality compared to pulsed accelerators.

When a polymer chain undergoes crosslinking, it becomes stronger due to the formation of additional covalent bonds between the polymer chains. These covalent bonds create a three-dimensional network structure, which enhances the mechanical properties of the polymer.

Here's a more detailed explanation of how crosslinking strengthens polymer chains:

Increased Interchain Bonding

Before crosslinking, polymer chains are typically held together by weaker intermolecular forces, such as van der Waals forces or weak dipole-dipole interactions. These interactions are relatively weak compared to covalent bonds. However, during crosslinking, new covalent bonds form between adjacent polymer chains, resulting in stronger interchain bonding. The covalent bonds provide a more robust and permanent connection between the chains, leading to increased strength.

Load Distribution

Crosslinking promotes load distribution throughout the polymer network. When an external force is applied to a crosslinked polymer, the stress is distributed across multiple chains instead of being concentrated on individual chains. This distribution of stress prevents localized chain movement or deformation, resulting in improved mechanical strength and resistance to deformation.

Network Formation

The crosslinked polymer network forms a continuous three-dimensional structure. This structure reinforces the polymer chains and provides structural integrity. When a force is applied, the network resists deformation and provides support to the polymer chains, preventing them from easily sliding or moving past each other. This interlocking network arrangement contributes to the overall strength of the polymer.

Improved Energy Dissipation

Crosslinking enhances the ability of the polymer to dissipate energy. When a force is applied, the crosslinked structure can absorb and distribute energy more effectively, reducing the likelihood of fractures or failure. The covalent bonds formed during crosslinking act as energy sinks, helping to absorb and dissipate mechanical energy, thus increasing the strength and toughness of the polymer.

EBXL Crosslinked Cable after 1 hour @240 °C

Non-Crosslinked Cable after 1 hour @200 °C

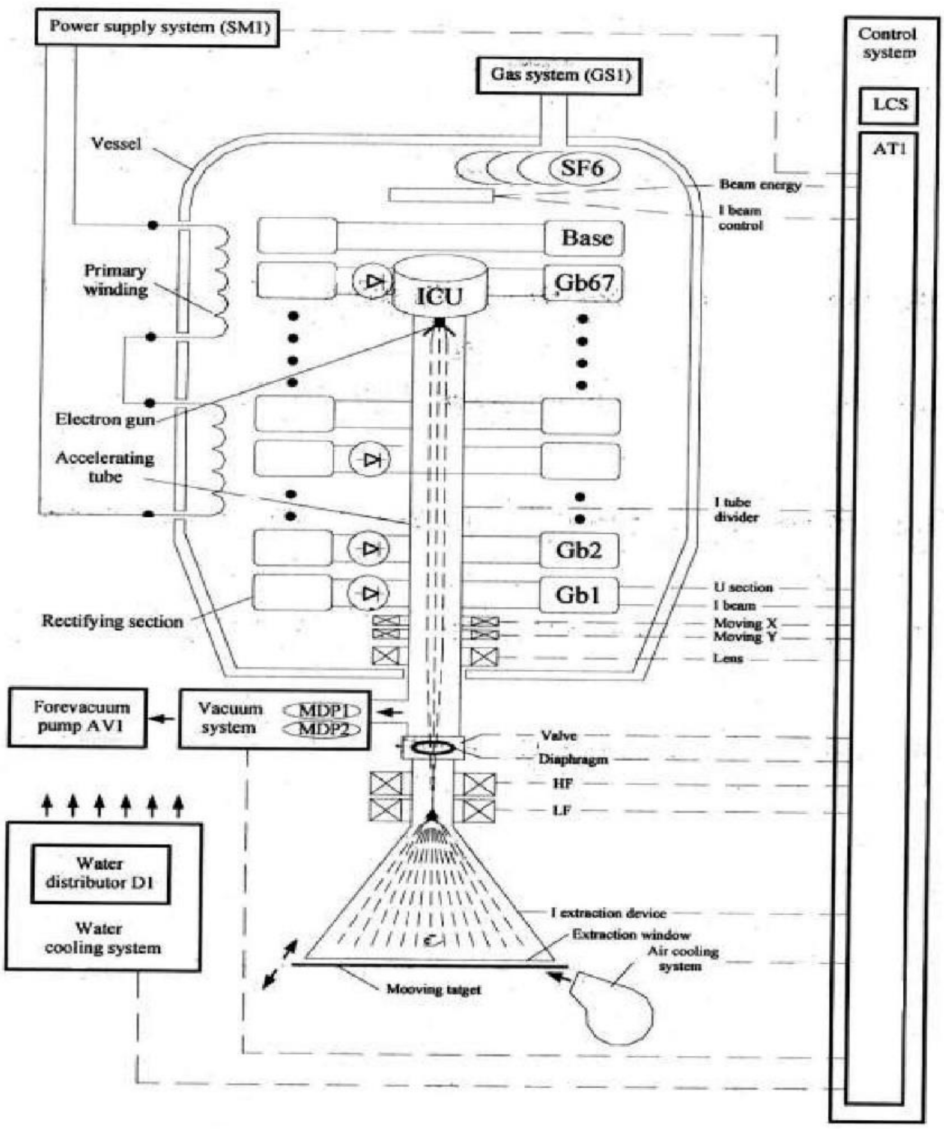
In electron beam accelerated wires and cables, heat shrink tubes, etc., cross linking is done either 2 or 4 sides in a figure of 8 method depending upon the insulation/sheathing wall thickness of outer diameter of the wires and cables.

Electron beam crosslinking enhances the cable's mechanical strength, making it more resistant to physical stress, including the application of heat from a soldering iron. This increased strength helps prevent damage or deformation during soldering. Additionally, the thermal resistance of the cable is improved, enabling it to withstand high temperatures without significant degradation.

Furthermore, electron beam crosslinking enhances the cable's resistance to soldering heat and the associated thermal cycling. This ensures that the cable maintains its structural integrity and electrical performance even under prolonged exposure to high temperatures during soldering. The improved properties after electron beam crosslinking and the soldering iron test contribute to a more reliable and durable cable that meet the requirements of various applications in the electronics and electrical industries offering very high operating temperature requirements.

5. Equipment for Electron-Beam Crosslinking

Electron beam equipment consists of several essential components that work together to generate and control high-energy electron beams. These components include:



Electron Gun

The electron gun is responsible for producing a stream of high-energy electrons. It typically consists of a cathode, an anode, and a focusing system to generate and shape the electron beam.

Accelerating System

The accelerating system uses electric fields to increase the energy of the electron beam. It typically includes a series of electrodes that create a high-voltage gradient, accelerating the electrons to the desired energy level.

Beam Control System

The beam control system regulates the intensity, position, and shape of the electron beam. It includes devices such as magnetic lenses, steering magnets, and scanning systems to focus and direct the beam as required.

Vacuum System

Electron beam equipment operates under vacuum conditions to prevent electron scattering and interactions with air molecules. The vacuum system includes pumps, valves, and chambers to create and maintain the necessary vacuum environment.

Beam Monitoring and Measurement

Various sensors and detectors are employed to monitor and measure the characteristics of the electron beam, such as current, energy, and beam profile. These measurements ensure proper beam control and optimization.

Safety Systems

Electron beam equipment incorporates safety features to protect operators and prevent potential hazards. These may include interlocks, shielding, and monitoring systems to ensure safe operation.

By integrating these components, electron beam equipment enables precise control and manipulation of high-energy electron beams for a wide range of applications, including the modification, crosslinking, and sterilization of materials in the cable industry and beyond.

6. Applications of Electron-Beam Cross-linked Cables

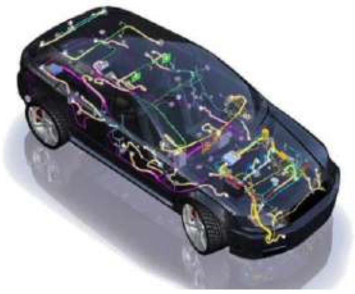
Electron beam cross-linked cables find application across various industries due to their enhanced properties and reliability. Some notable applications include:

Power Transmission, Distribution and Control

Electron beam cross-linked cables are widely used in power transmission and distribution systems. They offer improved insulation properties, increased thermal resistance, and better mechanical strength, allowing for efficient and reliable electricity transmission over long distances

Automotive & Rolling Stock

Cross-linked cables are employed in automotive/ rolling stock applications, such as wiring harnesses and battery cables. They provide excellent resistance to heat, chemicals, and mechanical stress, ensuring reliable electrical connections in demanding automotive / rolling stock (metro's & long-haul trains) environments.



Aerospace and Defence

In the aerospace and defence sectors, electron beam cross-linked cables are utilized for aircraft wiring, communication systems, and missile applications. Their enhanced properties, including high & low temperature resistance, radiation resistance, and improved fire performance, make them suitable for critical and high-demand applications.

Renewable Energy

Cross-linked cables play a vital role in renewable energy systems, including solar and wind power. They can withstand the harsh outdoor conditions, such as UV radiation and extreme weather & temperatures, while maintaining electrical integrity and performance.

Industrial, Appliances, Mining and Construction

Electron beam cross-linked cables are used in various industrial, appliances and construction applications, such as control cables, motor leads, and instrumentation cables. Their durability, resistance to chemicals, and mechanical robustness make them suitable for harsh industrial environments.

Marine and Offshore

Cross-linked cables are employed in marine, aircraft carriers, submarines, star cruise and offshore applications, where they provide excellent resistance to moisture, saltwater, and mechanical stresses. They are used in shipbuilding, offshore platforms, and underwater installations. The unique properties of electron beam cross-linked cables make them a preferred choice for applications where reliability, durability, and performance are paramount, enabling safe and efficient operations across diverse industries.

7. Other applications of electron beam cross-linking

Foam and Sponge Materials

Electron beam cross-linking is employed in the production of foam and sponge materials used in various industries, including automotive, construction, and packaging, to enhance their structural integrity and resilience.

Fiber Optic Cables

Electron beam cross-linking is utilized in the manufacturing of fibre optic cables, ensuring improved mechanical strength and stability, as well as enhanced resistance to environmental factors such as temperature and humidity.

Electrical Insulation Tapes

Electron beam cross-linking is applied in the production of electrical insulation tapes, providing them with increased heat resistance, electrical insulation properties, and overall durability.

Semiconductor Industry

Electron beam cross-linking is used in the fabrication of semiconductor devices to modify and improve the properties of polymers used as insulation, dielectric layers, and encapsulation materials.

Sterilization of Packaging

Electron beam cross-linking is employed for sterilizing packaging materials, such as pouches and trays, in the food and medical industries to ensure the safety and longevity of packaged products.

Adhesive and Sealant Applications

Electron beam cross-linking is utilized in the formulation of adhesives and sealants, improving their bonding strength, chemical resistance, and overall performance in various industries, including automotive, construction, and electronics.

Closing

More than 20 years Siechem has established as India's no.1 specialist wire and cable manufacturer having developed over 20 million part nos. for various segments, hostile environments, tailor made power, control, instrumentation, data, signalling, networking sensor cable solutions and supplied 100's millions of kilometres of wires and cables to many OEM's, Tier 1 customers and varieties of projects for over 60 countries across the World.

Siechem's PW125 and Sietherm 155 EBXL wires and cables are best suited for many tough working environments. The catalogues for entire range of EBXL wires and cable's for other applications too can be downloaded at www.siechem.com

Electron beam cross-linked cables have established enhanced electrical, mechanical, thermal, weathering, UV, fire, abrasion, flexibility and special features tailor made to every customer requirement. No other cross-linking technology has ever challenged or come close to EBXL processing offering long life, robustness, reliability and safety.

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