Determination of WUBHS speed range for electron beam irradiation of wire and cable

Siti Zulaiha Hairaldin1,a), Ruzalina Baharin1, Shahrina Akma Mansur1, Mohd Suhaimi Jusoh @ Yusoff1, Mohamad Zulhailmee Mohd Zainal1, Azmi Ali1

1Electron Beam Irradiation Centre (ALURTRON), Malaysian Nuclear Agency, Bangi, 43000 Kajang, Selangor, Malaysia.

a) sitizulaiha@nm.gov.my

Abstract. The electron beam machine was installed in 1991 at Nuclear Malaysia Agency. There are about one million meters of wire and cable irradiated in the facility every year. Electron beam irradiation introduces to crosslink the polymer material for high-performance wire and cable for the automobile industry. ALURTRON is facing few challenges while of irradiating wire and cable to determine the speed and to comply with the product quality (QC) test. The uncertainty of Wire Under Beam Handling System (WUBHS) speeds while irradiating wire and cable due to different situations. In this study, Polyethylene (PE) and Polyvinylchloride (PVC) wire and cable irradiated with electron beam irradiation at suitable speed based on the material, size and calculation etc. The sample analyse with hot set and gel content test. The speed decided at range 220-232, 180-196 and 180-194 m/min for 6.4 mm tube, 9.5 mm tube and PVC wire respectively.

1. Introduction

The EPS3000 providing irradiation services for various product treatment and purposes. Few type of product irradiated in the facility such as silicon wafer, wire, tubing, polymer, hydrogel, electronic component, gemstone [1], waste water treatment etc. ALURTRON is certified to ISO 9001 Quality Management System (QMS) since 2003. With the implementation of ISO 9001:2015 at the facility the data record becomes more systematic and structured. Quality assurance ensures the intended process (machine, material, man method) is available to be carried out and compliance with the standard. Meanwhile, quality control is a process to control the output of the process to minimize the variation of quality, avoid reject or undelivered products.

Radiation for an insulated wire and heat shrinkable tube has been widely used for the last 50 years, starting in 1950s [2]. In ALURTRON, we started to irradiate for wire & cable since the installation of Wire Under Beam Handling System in 1994 [3]. Usually, polymeric material with high molecular weight is used for electron beam irradiation to improve the material properties. Few types of polymer widely used electron beam accelerator in commercial industry: Polypropylene (PP), Polyethylene (PE), Polyvinylchloride (PVC), nylon, Ethylene-propylene-diene (EPDM), etc. The 3.0 MeV EPS3000 equipped with product handling system. The Product handling system is mechanical equipment that moves products from one location to the irradiation room. Two different types of product handling available in ALURTRON: 1) toe conveyer and 2) Wire Under Beam Handling System (WUBHS). The toe conveyer is used for flat product while the WUBHS is for wire & cable handling.
The product needs to pass the test at a certain range. In this study, the gel test will be matched with the hot set result and will be used as a reference by the electron beam (EB) machine operator. However, the problem with irradiation of wire and cable is the uncertainty of speed while irradiating different batch of samples. The speed keeps changing and not fixed at only one speed. ALURTRON is committed to ISO standard and the implementation. Therefore any change must be recorded and shall be evaluated occasionally. This paper aims to determine the speed range of WUBHS processing parameter for data record improvement.

2. Material and Methods

Samples of wire and cable diameter size irradiated with electron beam machine (EPS 3000) according to irradiation process procedure in Quality Manual. Material type of wire and tube is polyvinylchloride (PVC) and polyethylene (PE) respectively (Table 1).

| Samples | Material | Diameter size (mm) |
|---------|----------|-------------------|
| Wire    | PVC      | 0.5, 0.85, 1.25   |
| Tube    | PE       | 6.4               |
| Tube    | PE       | 9.5               |

The parameter of the electron beam machine is decided by considering a few factors which is material, size, hot set test, and gel content result, etc. The speed of WUBHS estimated by the equation:

$$\text{Speed (m/min)} = \frac{\text{Beam Current} \times \text{No. Of Turns} \times \text{K Factor}}{\text{Dose (Mrad)}}$$  \hspace{1cm} (1)

The speed calculated based on the required dose and quality test data. Two types of test available in the QA/QC laboratory for wire and cable testing: 1) hot set and 2) gel content. The hot set test measured the heat expansion behaviour of the material. The test conducted as a preliminary test and used as a preference due to quick and reproducible results. The gel content test measures the crosslinked degree amount of a polymeric material and it is a compulsory test required by the company. However, the gel test takes about 5 days to complete. The hot set test takes a shorter time compared to the gel content test, which is about 25-40 minutes per sample only. Therefore, the hot set test used as a preliminary reference for QC process due to the shorter time required.

The diameter of the sample measured using the micrometer caliper (MITUTOYO/CD-15APX, Japan). UV-VIS spectrophotometer machine (UV-VIS Spectronic Genesis 5, Thermo Electron Corporation) to measure absorbed dose by the product. Cellulose triacetate (CTA) dosimeter film (FTR-60, Fujifilm, Japan) used as a dosimeter due to wide range of dose 5-300 kGy and provide reliable data and suitable for our facility application.

Load mass for the hot set test was determined by balance (Sartorius/BSA 6202S) Germany. The dumbbell cutter used to cut the 9.5 mm tube. Samples were put in Kendro oven at a specific temperature. Stopwatch to measure 15 minutes hot set test heating timing following procedure of hot test test (Quality manual). Elongation of the sample measured by laser teleheight equipped with an oven. Tetrahydrofuran (THF) and Xylene used as a solvent for PVC wire and PE tube respectively following procedure. All data recorded, compiled and analyzed.
3. Material and Methods

Samples of wire and cable diameter size irradiated with electron beam machine (EPS 3000) according to irradiation process procedure. Material type of wire and tube is polyvinylchloride (PVC) and polyethylene (PE) respectively (Table 2).

| Table 2. Samples of wire and tube irradiation. |
|-----------------------------------------------|
| Samples | Material | Diameter size (mm) |
| Wire    | PVC      | 0.5, 0.85, 1.25   |
| Tube    | PE       | 6.4               |
| Tube    | PE       | 9.5               |

The diameter of the sample measured using the micrometer caliper (MITUTOYO/CD-15APX, Japan). UV-VIS spectrophotometer machine (UV-VIS Spectronic Genesis 5, Thermo Electron Corporation) to measure absorbed dose by the product. Cellulose triacetate (CTA) dosimeter film (FTR-60, Fujifilm, Japan) used as a dosimeter due to wide range of dose 5-300 kGy and provide reliable data and suitable for our facility application.

Load mass for the hot set test was determined by balance (Sartorius/BSA 6202S) Germany. The dumbell cutter used to cut the 9.5 mm tube. Samples were put in Kendro oven at a specific temperature. Stopwatch to measure 15 minutes hot set test heating timing following the Hot Set procedure (Quality manual). Elongation of the sample measured by laser teleheight equipped with an oven. Tetrahydrofuran (THF) and Xylene used as a solvent for PVC wire and PE tube respectively. All data recorded, compiled and analyzed.

4. Results

The Speed data of each sample indicate in Figure 2. The lot no refers to the batch delivery of the product in the current month. The uncertainty of WUBHS speeds while irradiating wire and cable due to several reasons. The WUBHS Speed is fluctuating. It is not convenient for the operator to fill in the process change form each time the speed change. The variation of speed may be due to 1) different batch of product and involves different blending process. Another crucial factor also contributes to changing of speed which is 2) different supplier of raw material and 3) change of formula etc. Situation 2) and 3) is in control, the customer will inform us if they do change the formula or supplier. However, for situation 1) is very subjective which is no reference and indication of record available/provided by customer to refer to.
Figure 1 (a-c). WUBHS speeds data analysis for wire and cable.
Parameter for electron beam processing for wire decided in Table 2. The word “Before” refers to the last parameter used (single speed data record) and “After” is refer to the flexible speed with minimum and maximum speed. This data recorded in the irradiation process control form (EBM/FO/OP/02) in Table 3 and 4. Therefore, the process of data recording and filing is more effective by applying the range of speed data record instead of a single speed.

Table 3. The Parameter of electron beam processing for wire.

| Product       | Before | After  |
|---------------|--------|--------|
| Wire (all size) | Parameter/size (mm) | PVC | PVC |
| Acc. Voltage (MeV) | 1.0 | 1.0 |
| Beam Current (mA) | 30 | 30 |
| No. turns | 54 | 54 |
| Dose (kGy) | 90 | 90 |
| Speed (m/min) | 187 | 180-194 |

Parameter of tubes decided as indicate in Table 4:

Table 4. The Parameter of electron beam processing for 6.4 mm tube and 9.5 mm tube

| Product       | Before | After  |
|---------------|--------|--------|
| Tube | Parameter/sample size (mm) | 6.4 | 9.5 | 6.4 | 9.5 |
| Acc. Voltage (MeV) | 2.5 | 2.5 | 2.5 | 2.5 |
| Beam Current (mA) | 30 | 30 | 30 | 30 |
| No. turns | 64 | 64 | 64 | 64 |
| Dose (kGy) | 160 | 190 | 160 | 190 |
| Speed (m/min) | 230 | 194 | 220-232 | 180-196 |

5. Conclusion

Tube and wire product speed are decided at range 220-232, 180-196 and 180-194 m/min for 6.4 mm tube, 9.5 mm tube and PVC wire respectively. Speed suggested being recorded as a range type instead of a single data speed parameter.

6. References

[1] Idris S, Hairaldin S Z, Tajau R, Karim J, Jusoh S, and Ghazali Z, Ahmad S 2015 An experience of electron beam (EB) irradiated gemstones in Malaysian Nuclear Agency AIP Conf. Proc. 1584(1) p 170-174.
[2] Cleland M R 2006 Industrial applications of electron accelerators CERN Accelerator School:Small Accelerators, Proc. p 383-416.
[3] Hashim S A, Jahar S, Muhamad A 2011 Electron beam cross linking service for tubular products: Malaysian Nuclear Agency's experience Nucl. Tech. Conv. 2011 (Malaysia).
[4] Quality Manual 2019 Electron Beam Irradiation Centre (ALURTRON) (Bangi: Malaysian Nuclear Agency)
Acknowledgment
The authors wish to express their sincere thanks to Electron beam Irradiation Centre (ALURTRON) facility and personnel who have worked and contributed to carrying this experiment.