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Effect of Different Radiation Doses on the Electrical and Mechanical Properties of PVC Insulation Cable

Helmi Hafizul Hakim Asrol[1], Norazrina Mat Jali[1,*], Nor Azwin Shukri[2] , Norshafarina Ismail[2] , Mohd Taufiq Ishak[1], Maidiana Othman[1]

[1] Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, Sungai Besi, Malaysia
[2] Radiation Processing Technology Department, Agensi Nuklear Malaysia, 43000 Kajang, Malaysia

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ABSTRACT

The cable sheath has a very important function as an initial barrier to the spread of flame because it has a significant effect on fire expansion. Thus, it is of great significance in this project to carry out research on modification for cable sheath material to enhance its properties. In this project, the project emphasized the effect of different ratio of PVC with TMPTA as a crosslinking agent. The PVC was exposed to electron beam irradiation to improve the crosslinking properties of the cable sheath. Optimum radiation dose for crosslink through electron beam irradiation was determined using gel content test. For mechanical test, tensile test was conducted to determine mechanical properties of unirradiated and irradiated the composition. To determine electrical properties, conductivity and resistivity tests were carried out. Main outcome from this project is different ratio of PVC and TMPTA compound enhance with crosslink method to the PVC will contribute different properties of mechanical and electrical. The result of gel content test shows increasing irradiation dose was accompanied by increasing gel fraction for all PHR samples. The highest degree of crosslinking recorded at PHR 5 with 100kGy which is 74.186%. For tensile test, it shown that PHR5 exhibited the highest tensile strength and elastic region which is 21.12 N/mm2 while elongation at break was the lowest which is 14.4997 mm at doses 100kGy. For electrical test, at 50 Hz, PHR 5 exhibited the lowest conductivity of 0.92×10^{-8} S/cm at 100 kGy.

1. Introduction

Cable fires in buildings have a significant probability to occur at any time in the working process which results in incidents that kill and injure thousands of people every year besides the significant loss and damage. According to fire statistics released by the Fire and Rescue Department (BOMBA), 34,902 cases of fire were recorded in 2022 with the majority of fire emergencies occurring in residential buildings, followed by public locations such as hospitals, religious institutions, schools and universities [1]. Based on their forensic data, the most frequently reported causes of the fire were electrical short circuits, electrical overloading and resistance heating.

* *Corresponding author.*
E-mail address: norazrina@upnm.edu.my

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PVC (polyvinyl chloride) products account for roughly 20% of all polymeric materials utilized as a sheath material because of its outstanding electrical insulation capabilities, mechanical performance, and inexpensive cost. However, the development of new modern formulations is important to note that the addition of different types and formulation of material may significantly influence mechanical and electrical properties [2,3].

An alternative method to enhance the properties of PVC is by conducting crosslink method. Cross link formation is the bonding of several polymer chains to each other because of forming a covalent bond [4] . There are many ways to activate this chemical reaction, including by using irradiation such as electron beam exposure, gamma rays or UV light [4].

When a mechanical load is applied to a PVC cable, it can potentially cause damage to the cable insulation or conductor, which can lead to a short circuit or even a fire under certain conditions. If a mechanical load is applied to a PVC cable, it can cause the insulation to crack or break, exposing the conductor underneath. This can create a short circuit if the exposed conductor comes into contact with another conductor or a grounded surface, which can lead to electrical arcing and overheating. The risk of short circuit or fire due to mechanical stress on a PVC cable depends on several factors, including the degree of mechanical stress, the condition of the cable insulation, and the current-carrying capacity of the cable [5].

Since fires are often associated with the ignition cause by short circuit in cable products, the development of new modern formulations of PVC compositions with improved performance properties is important for production of PVC cable. The formulation of PVC with filler is very significant as a wide range of chemical compounds are used at different application. The choice of a composition for a particular polymer is based on its effectiveness, safety, environmental friendliness, and cost [4]. It is important to note that the addition of different type and formulation of material may significantly influence mechanical and electrical properties [6]. Synergistic combinations of the various elements can also be considered for better performance.

In addition, the cross-linking method has been proved to improve the mechanical and electrical properties of PVC. However, its effectiveness depends on the specific application requirements and processing conditions. By optimizing the degree and density of crosslinking, it is possible to tailor the material properties to meet specific performance requirements and improve its overall functionality [7]. Thus, this project was conducted to observe the influence of different composition and radiation dose on these properties.

Radiation-induced crosslinking has been shown to improve the polymer/polymer and polymer/particle bonding strength, resulting in increased tensile strength, mechanical stability, heat resistance, as well as aging and stress cracking resistance[8]. Cross-linked polymer such as PVC and polyethylene (PE) is the most widely used insulation material for electrical cable with enhanced stability against electrical breakdown. Crosslinking allows wires and cables to be utilized at temperatures above their intrinsic softening point for an extended period and also protects the insulations from severe deformation for high currents and temperatures. However, the irradiation dose must be kept as low as possible to avoid excessive crosslinking, which causes the polymer materials to become brittle[9].

For this reason, a crosslinking accelerator such as trimethylol propane trimethacrylate (TMPTMA) is added to the polymer blend to reduce the dose required to achieve optimum properties. This crosslinking accelerator generates a high concentration of radicals during irradiation, allowing crosslinking to be accomplished at much lower doses and reducing the degrading impact caused by HCI evolution. The final extent of PVC crosslinking is a function of irradiation dose, crosslinking accelerator, temperature and the presence of plasticizer[10]. Therefore, by tuning the processing conditions of radiation-induced crosslinking, the PVC blend can be modified with FR compounds with desired flammability properties without jeopardizing the physical properties of PVC

Many studies have been conducted and show that the composition of the material and radiation dose can have a significant impact on the mechanical and electrical properties of PVC (polyvinyl chloride). The effect of composition and radiation dose on the mechanical and electrical properties of PVC can depend on several factors, such as the type and concentration of additives, the type and energy of radiation, and the processing and testing conditions[11. From the research, certain composition and cross-liking methods do not give expected result of the properties in certain condition. As an example, no apparent effect on tensile strength for certain formulation was observed due to the increase of irradiation dose as shown in Table 2.3. From six sample, only sample with PHR1 and 14 PHR 5 have a significant effect when exposed to radiation[12].

Besides, there is research found that tensile strength and elongation at break is decrease when concentration of additive increases. This may be attributed to excessive loading of fillers including thermal stabilizer, flame retardants and clay which lead to hindering the influence of irradiation and reagent [4]. They also reported that different composition in PVC can influence the electrical properties [6]. The conductivity of polymers can also be increased in several ways such as increasing the degree of polymerisation, increasing the pressure, raising the temperature or irradiation dose [13].

2. Materials and Methods

2.1 Material

Ingredients that will be used for material preparation are a commercial PVC resin and TMPTA as a cross linking that were supplied by Wonderful Ebeam Cable Sdn Bhd. In this experimental study, the specimen was prepared into five different parts per hundred resin (PHR) formulation with different amounts of cross-linking agent. The mixture was blended in Thermo Scientific HAAKE internal mixer. Then, hot press machine was used to prepare the desired shape for all testing.

2.2 Sample Preparation

Preparing specimen formulations was conducted by mixing and blending the PVC with additives in a molten state to achieve homogeneous blend using Thermo Scientific Haake internal mixer (Figure 1) before undergo irradiation process. The overall process of sample preparation is shown in Figure 2. To achieve homogenous blend, the composition was blended for 10 minutes. At first 2 minutes, only plasticizer PVC was added in the mixer to let the resin melt then after 2 minutes, the addictive was added and mix. The additives were mixed with the resin by using PHR formulations given in Table 1 as referred to the study by [13]. Figure 3 shows the specimen after mixing process.

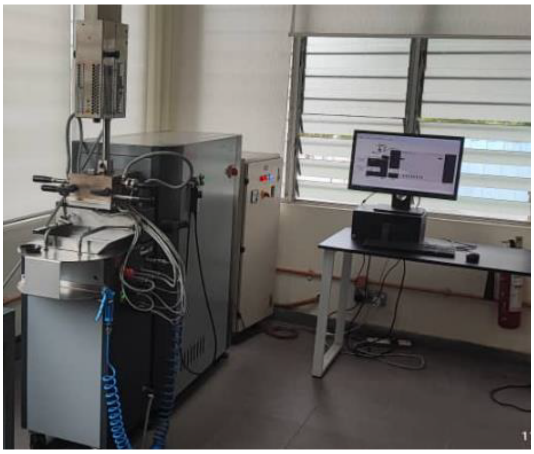

Fig. 1. Thermo Scientific Haake internal mixer

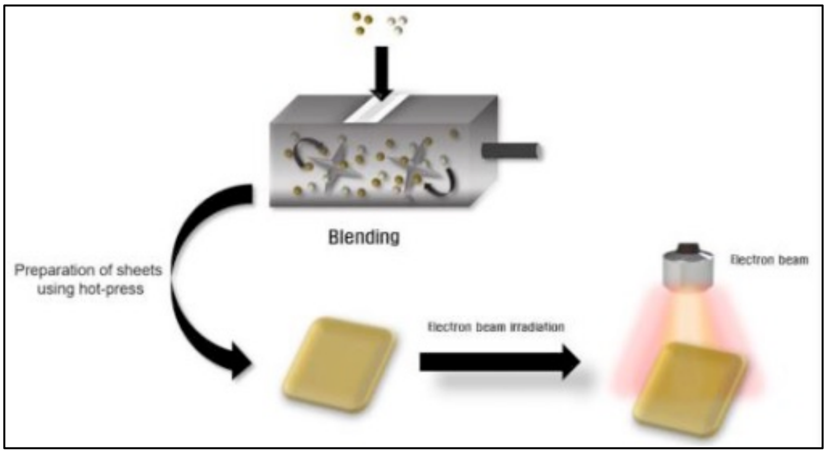

Fig. 2. The overall process of sample preparation starting from blending, hot press and radiate

Table 1
PHR formulation of PVC

Component	PHR	Additives (TMPTA) (g)	Plasticizer PVC resin(g)	Total (g)
crosslinker 1	1	0.65	64.35	65
crosslinker 2	2	1.3	63.7	65
crosslinker 3	3	1.95	63.05	65
crosslinker 4	5	3.25	61.75	65
crosslinker 5	7	4.55	60.45	65

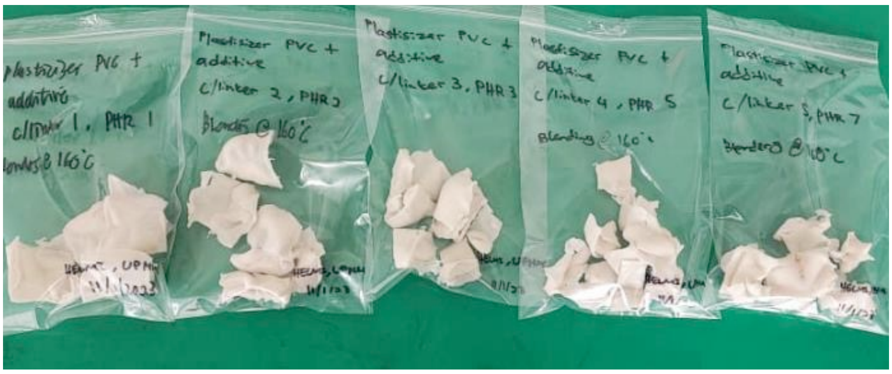

Fig. 3. Final product after mixing process (PVC with different PHR)

Then the final process is hot press process to produce the desired shape of the specimen using compression moulding machine as shown in Figure 4. For hot press process, total time to complete one press sample is 15 minutes where there are 3 process which are pre heat, full press, and cooling with 5 minutes duration for each process. The temperature for pre heat and full press is 160°C. Figure 5 shows specimen after hot press.

Fig. 4. TISB 50T Compression moulding machine

Fig. 5. Specimen after hot press were left for at least 24 hours in room temperature before further testing

2.3 Irradiation Process

Irradiation process was carried out in Malaysian Nuclear Agency's ALUTRON laboratory with the electron beam radiation dose within 0 to 100 kGy using the EPS-3000 3.0 MeV high-energy machine. In this process, electron beam irradiation was performed in the range of 60, 80 and 100 kGy. Specimen without irradiation was (0 kGy) was reserved as a reference specimen. Thus, PVC samples should be placed in the irradiation chamber and exposed to the electron beam at the appropriate dose and energy. To examine the crosslinking of PVC after irradiation process, gel content testing was carried out.

2.4 Gel content test

Gel content analysis was carried out to measure the amount of crosslinking induced by irradiation. A weight of 0.2g specimen was cut before putting into a single-use stainless steel wire mesh pouch (size 4cm x 4cm). They were fitted into a 30mL Soxhlet extractor and extracted for 24h using Tetrahyrofuran (THF) as a solvent. The insoluble portion was dried and weight to measure the degree of crosslinking by using the equation as follows:

$$\text{Degree of crosslinking: } \frac{Wf \times 100\ \%}{Wi} \qquad (1)$$

Where:
Wf : Final weight (insoluble part)
Wi = Initial weight of the sample

2.5 Tensile test

The tensile test was performed to determine mechanical properties of un-irradiated and irradiated PVC specimen by applying a tensile force to a test specimen until the specimen is pulled to failure using Universal Testing Machine, Shimadzu AG-X. Therefore, this tensile test is also important as to study the elastic properties of irradiated XLPE at different dose of electron beam because different dose will result in different degree of crosslinking.

The standard test method is using ASTM 27D1882-L, and the specimen was cut using specific size of cutter according to standard test measurement as shown Figure 6.

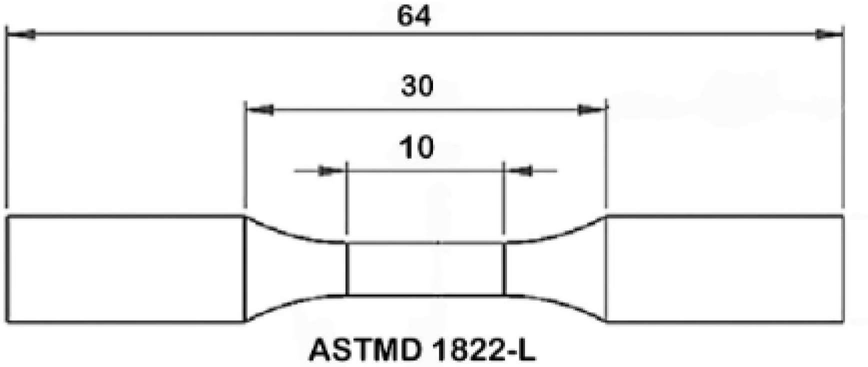

Fig. 6. Detail measurement for tensile test sample (ASTMD 1822-L)

Before the test was conducted, the parameter of each specimen such as thickness and wide was taken. The gauge length was set at 10 mm and the crosshead speed of 10 mm/min was used. The test was performed at 25 ± 3 °C. The five samples from each composition were tested and the average values were taken.

2.6 Conductivity test

For conductivity testing, the electrical test for determining the conductivity of PVC was conducted by 16451B Dielectric Test Fixture as shown in Fig.7. Conductivity is calculated from the measured resistance and dimensions of the specimen. Conductivity is defined as the ratio of the density of this current to the strength of the electric field. The accuracy and conveniences with which resistance can be measured depend on the actual resistance of the specimen.

3. Results and Discussion

3.1 Gel Content Result

The gel content of the irradiated sample was measured to quantify the amount of crosslinking induced by irradiation. Percentage of gel content is indicating the degree of cross linking in the material. The gel content of plasticizer PVC samples for PHR 1, PHR 2 and PHR 5 with TMPTA compound were determined by solvent extraction procedure and reported in Table 2. It is observed that for 0kgy, all PHR have low degree of gel content because the samples did not expose to radiation. The values of gel content recorded is only 4.289%, 4.87% and 3.284% for PHR 1, PHR 2 and PHR5 respectively. However, increasing irradiation dose was accompanied by increasing gel fraction for all PHR samples.

Based on Figure 8, there is no significant different degree of crosslinking between PHR at 60 kGy but if compared to 0 kGy, it was increase drastically after expose to 60kgy irradiation dose which are 67.685%, 64.834% and 66.741% for PHR 1, PHR2 and PHR 5 respectively. At 80 kGy, PHR 1 recorded a lower degree of crosslinking which is 52.972% followed by PHR 2 and PHR 5 which is the higher which 62.204% and 72.311% respectively. The pattern of graph is same for 100 kGy, which PHR 1 still the lowest followed by PHR 2 and PHR 5 is the higher with 53.528%, 65.618% and 74.186% respectively.

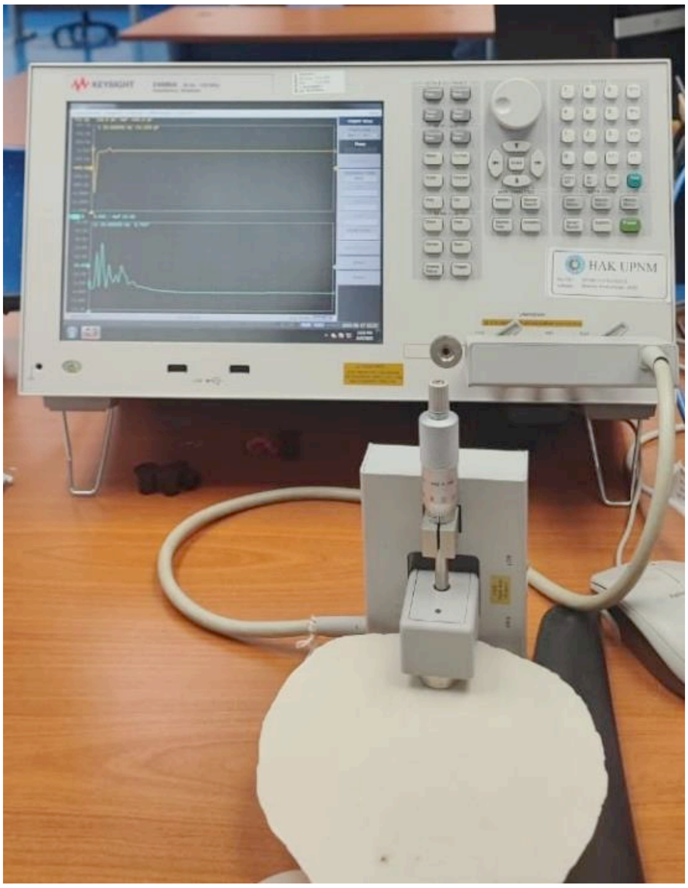

Fig. 7. 16451B Dielectric Test Fixture

Table 2
Average gel content (%) for PHR 1,2 and 5 with different radiation dose

Radiation doses (kGy)	Average gel content (%)		
	PHR 1	PHR 2	PHR 5
0	4.289	4.87	3.284
60	67.685	64.834	66.741
80	52.972	62.204	72.311
100	53.528	65.618	74.186

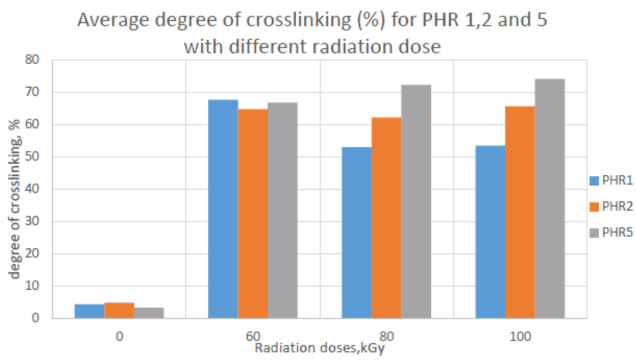

Fig. 8. Average degree of crosslinking for PHR 1, PHR 2 and PHR 5

Addition of TMPTA to plasticiser PVC and irradiation of the compound with electron beam produces a gel as a result of network formation in the compound system. It was proved that the gel content increased when there are more crosslink agent and higher radiation dose. This is because there is high probability of recombination of radicals between the polymers[6]9. It is known that addition of a plasticizer influences the rheological properties of the compound which results in higher mobility of the system causing an improvement on the recombination rate of the radicals formed during PVC irradiation. Generally, the extent of radiation crosslinking of polymers can be estimated from gel fraction determination and modulus measurements. However, in the presence of low molecular weight components, such as, plasticizers, the method of gel-determination can give erroneous information due to binding of the low-molecular weight component with and without crosslinking [14].

3.2 Mechanical Properties of PVC and TMPTA Compound

To evaluate the mechanical behaviour, tensile test has been performed at room temperature (25°C) for PVC samples before and after irradiation. Testing was measured on dumbbell specimens using a Universal Testing Machine, Shimadzu AG-X in accordance with ASTM D1882-L. The mechanical properties that observed in this experiment were ultimate tensile strength and elongation at break which determined from the stress strain curve.

By plotting stress against strain, the graph can reveal important information about the material's stiffness, strength, and ductility. The result reported here are the ultimate tensile strength and elongation at break of averages three samples per formulation which are PHR1, PHR2 and PHR5 with different doses 0 kGy, 60 kGy, 80 kGy and 100 kGy. The investigation was carried out by making comparison of the stress strain curve between different radiation dose to each PHR and comparison between different PHR in each radiation doses.

3.2.1 Effect of different composition and radiation doses on mechanical properties

Specimens for tensile test after irradiation with different radiation dose is shown in Figure 9. Changes of colours can be clearly seen as the radiation increases from 0-100 kGy.

Ultimate tensile strength (UTS) and elongation at break (EAB) are important mechanical properties to observe when analyzing the performance of PVC and TMPTA compound for different PHR (Parts per Hundred Resin) and different radiation dose because it provides information on the material's strength, durability, and flexibility under different conditions. The stress-strain curve by radiation doses for each PHR are presented in Figure 10. From the stress-strain curve obtained, the results for ultimate tensile strength and elongation at break can be presented as shown in Table 3, Figure 10,11 and 12.

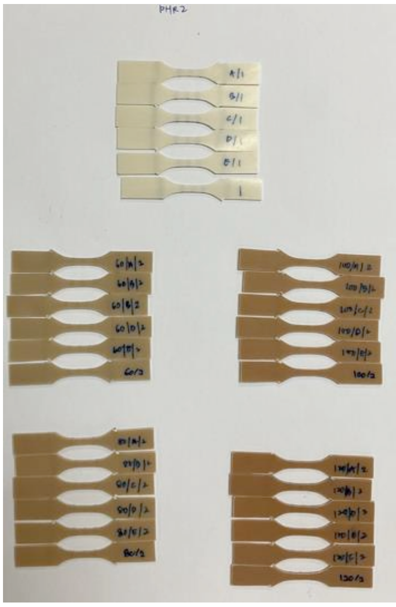

Fig. 9. Specimens for tensile test after different dose of electron beam irradiation

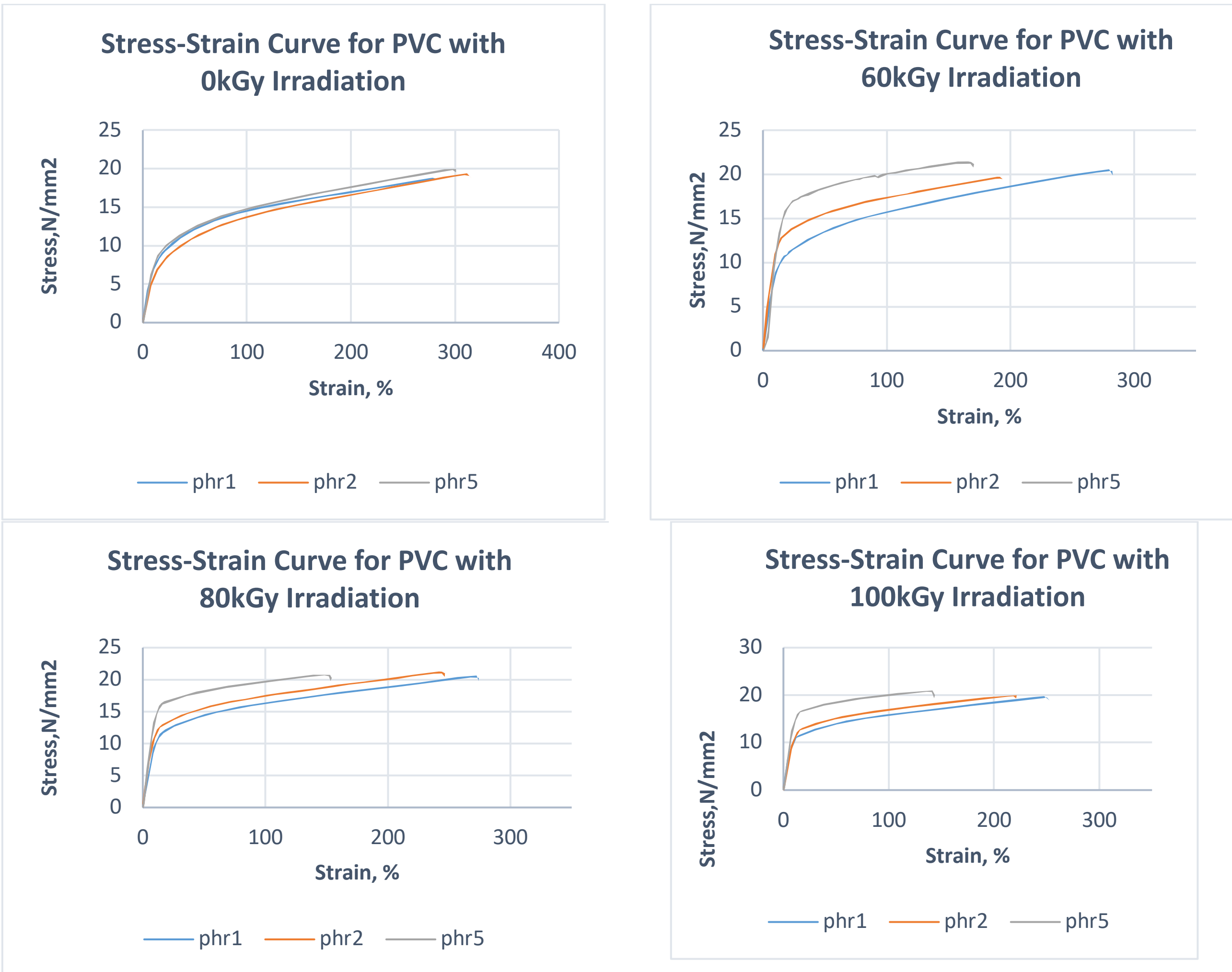

Fig. 10. Strain Strain Graph for PHR 1, PHR 2 and PHR 3, (a) 0kGy, (b) 60kGy, (c) 80kGy, (d) 100kGy

Based on Figure 10(a), it shows that unirradiated sample (0 kGy) for all PHR have slight difference at trend. It shows that all PHR have almost the same properties for tensile strength and ductility. However, the trend changed significantly as the sample was exposed to radiation. Figure 10 (b), (c) and (d) shows PHR 5 has significant differences in tensile strength and elongation at break compared to PHR 1 and PHR 2.

Table 3
Average maximum strength of PVC for PHR1,2 and 5 at different doses

Average maximum strength of PVC, N/mm²			
Radiation dose (kGy)	PHR1	PHR2	PHR5
0	18.8909	19.4732	20.646
60	20.3112	20.3519	20.7875
80	19.9837	20.2018	20.8932
100	20.0283	20.2866	21.1244

Tensile strength is a measure of the maximum stress that a material can withstand before it breaks or deforms. Figure 11 shows the trend of average maximum stress of different PHR crosslink PVC at different radiation doses. An upward trend can be seen as the tensile strength for all PHR has slightly increased after the irradiation. The graph shows that the unirradiated samples (0 kGy) containing TMPTA compound have a lowest tensile strength compared to irradiated samples which are 18.8909 N/mm2, 19.4732 N/mm2 and 20.646 N/mm2 for PHR 1, PHR 2 and PHR 5 respectively. However, these samples obtain enhanced properties due to irradiation because the irradiated samples present higher mechanical resistance in comparison with unirradiated samples [3]. When compared by PHR, it shows PHR5 exhibited the highest tensile strength which are 20.646 N/mm2, 20.7875 N/mm2, 20.8932 N/mm2 and 21.1244 N/mm2 while PHR 1 has the lowest tensile strength which are 18.8909 N/mm2, 20.3712 N/mm2, 19.9837 N/mm2 and 20.0283 N/mm2 at 0 kGy, 60 kGy, 80 kGy and 100 kGy respectively. Tensile strength for PHR 5 increased by 8.4%, 2.3%, 4.4% and 5.2% compared to PHR 1 at 0 kGy, 60 kGy, 80 kGy and 100 kGy respectively.

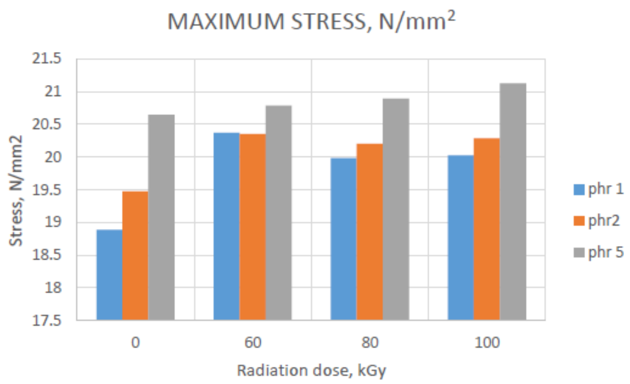

Fig. 11. Average maximum strength of PVC with different formulation and radiation doses

Plasticizer PVC is commonly added to PVC to increase its flexibility and processability. However, plasticizers can also reduce the tensile strength of the material by decreasing the cohesion between the polymer's chains. On the other hand, the formation of crosslinks can improve the strength and stiffness of the PVC by providing additional points of intermolecular interaction between the polymer chains. This can increase the cohesion between the chains and make it more difficult for the material to deform or break [15-16].

The elongation at break of PVC refers to the amount of deformation or stretching the material can undergo before it breaks. Figure 12 shows the trend of elongation at break of different PHR crosslink PVC at different radiation doses. A downward trend can be seen in Figure 12 that shows a reduction in the elongation at break as the radiation dose increases.

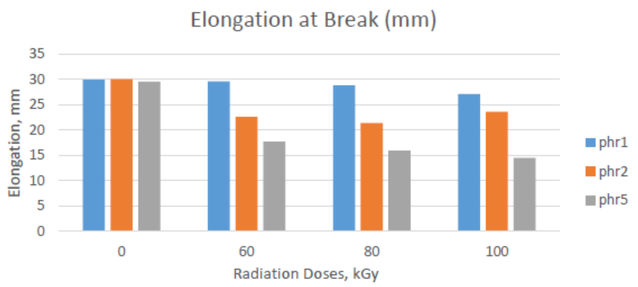

Fig. 12. Average elongation at break of PVC with different formulation and radiation doses

It also shows that for unirradiated samples (0 kGy) containing TMPTA compound have an almost same elongation at break and have the highest elongation compared to irradiated sample which are 29.9555 mm, 29.8897 mm and 29.5397mm for PHR 1, PHR 2 and PHR 5 respectively. For PHR 1, the elongation is 29.5822mm, 28.8506mm and 27.0939mm at 0kGy,80 kGy and 100 kGy respectively. The elongation at break has slightly decreased and not significant between unirradiated samples (0 kGy) and radiated sample (0kGy,80 kGy and 100 kGy) compared to PHR 2 and PHR 5. For PHR 2, elongation at break at 60 kGy, 80 kGy and 100 kGy are 22.5806 mm, 21.3738 mm, and 23.6122 mm. It decreased by 24.9 %, 28.96% and 21.52% at 60 kGy, 80 kGy and 100 kGy compared to 0 kGy. For PHR 5, elongation at break at 60 kGy, 80 kGy and 100 kGy are 17.7522 mm, 15.9572 mm, and 14.4997 mm. It decreased by 40 %, 45.98% and 50.91% at 60 kGy, 80 kGy and 100 kGy compared to 0 kGy. By PHR comparison It shows that PHR5 exhibited the lower elongation at break while PHR 1 has higher elongation at doses 60 kGy, 80 kGy and 100 kGy with a different by 40%, 44.69% and 46.48 respectively.

When a material is subjected to a tensile force, it deforms elastically at low stresses and strains, and begins to deform plastically at higher stresses and strains. At the point of failure, the material undergoes necking, which is a localized deformation that leads to a reduction in the cross-sectional area of the material. The elongation at break is a measure of the strain at which the material undergoes necking and failure [17].

For unirradiated specimens (0kGy), there are no effects of crosslink on the PVC and the elongation at break may not be significantly affected. However, as the radiation dose increases, the ionizing radiation can cause the formation of crosslink that can result in a reduction in the elongation at break. This is because the crosslinks restrict the movement of the polymer chains, reducing the material's ability to deform or stretch before breaking [18-19].

Based on Table 3, PHR1 contains 64.35g of plasticizer PVC and 0.65g additives (90% TMPTA crosslinking agent with 10% inert material). Meanwhile PHR 5 contains 61.75g of plasticizer PVC and 3.25g of additives. It means that the higher the PHR indicates that the less composition plasticizer and more additives in the sample. The higher tensile strength and lower elongation at break observed for PHR5 compared to PHR2 and PHR1 at each radiation dose could be attributed to several factors related to the composition of the materials. This composition difference could explain the observed difference in tensile strength and elongation at break.

Plasticizer PVC is commonly added to PVC to increase its flexibility and processability. However, plasticizers can also reduce the tensile strength of the material by decreasing the cohesion between the polymer’s chains. On the other hand, the formation of crosslinks can improve the strength and stiffness of the PVC by providing additional points of intermolecular interaction between the polymer chains. This can increase the cohesion between the chains and make it more difficult for the material to deform or break.

The presence of less plasticizer PVC in PHR 5 may increase the degree of chain entanglement in the material, which can lead to higher tensile strength but may also reduce the material's flexibility and elongation at break. Reducing their concentration can make the PVC more rigid and less able to deform under stress. Further increase in the concentration of TMPTA leads to plasticizing effect which gradually decreases the tensile strength [8]12. On the other hand, TMPTA is a crosslinking agent that can improve the mechanical properties of the material by forming a three-dimensional network when exposed to electron beam. This network can enhance the intermolecular interactions between the polymer chains, leading to increased strength and stiffness. In gel content test, it was proved that PHR 5 has the highest crosslink compared to PHR1 and PHR2. Therefore, the higher concentration of TMPTA in PHR5 could contribute to its higher tensile strength.

The presence of the inert material in additives may also play a role in the observed difference in tensile strength and elongation at break. The inert material may influence the mechanical properties of the material by altering the degree of interfacial bonding between the filler and the polymer matrix. If the inert material has a positive effect on interfacial bonding, this could lead to increased tensile strength. However, the inert material may reduce the mobility of the polymer chains and limit their ability to deform under stress, further contributing to the lower elongation at break [20-21].

Overall, the tensile strength and elongation at break are two important mechanical properties of a material that are often inversely related. In general, an increase in tensile strength can lead to a decrease in elongation at break [4]. When the tensile strength of a material increases, it means that the material can resist deformation and failure under higher stresses. This typically involves an increase in the intermolecular forces or crosslinking density within the material, which can improve its strength and stiffness. However, this increase in strength can also make it more difficult for the material to deform and neck before failure, resulting in a decrease in elongation at break. In other words, the material becomes more brittle and less ductile. the higher tensile strength and the lower elongation at break observed for PHR5 compared to PHR2 and PHR1 at each radiation dose could be attributed to the combined effect of having less plasticizer PVC, more TMPTA crosslinking agent, and the presence of inert material.

3.2.1 Stress- strain curve analysis of plasticiser PVC 1, PHR2 and PHR5 with different radiation doses

Further investigation into mechanical behaviour has been conducted by analysing the stress strain curve of plasticizer PVC for PHR 1, PHR 2 and PHR 3 at different radiation. The stress strain curve for PHR 1, PHR 2 and PHR 3 at different radiation dose are represented in Figure 4.5.

Different trend curves were observed especially the linear slope for each PHR at different radiation as shown in Figure 4.5. In Figure 4.5(a), PHR 1 shows slightly different strain for each radiation dose. A similar trend is observed for PHR 2 as shows in Figure 4.5(b) but there is steeper of linear for 60 kGy, 80 kGy and 100 kGy and the strain of these three doses is almost same compared to 0 kGy that have higher strain. In Figure 4.5 (c), PHR 5 there is a significant difference on tensile strength, strain, and the linear slope between 80 kGy and 100 kGy compared to 0 kGy and 60 kGy.

In addition, it was observed all the PHR begins to deform from elastic region to plastic region at almost same strain which is within average 20% but the stress at which the material begins to deform plastically for each radiation is different for every PHR. Overall, the yield strength was increased as the radiation dose increase depending on the PHR formulation. This may be due to crosslink formation and the plasticizer or crosslink agent compound that influence the mechanical properties as have been discussed.

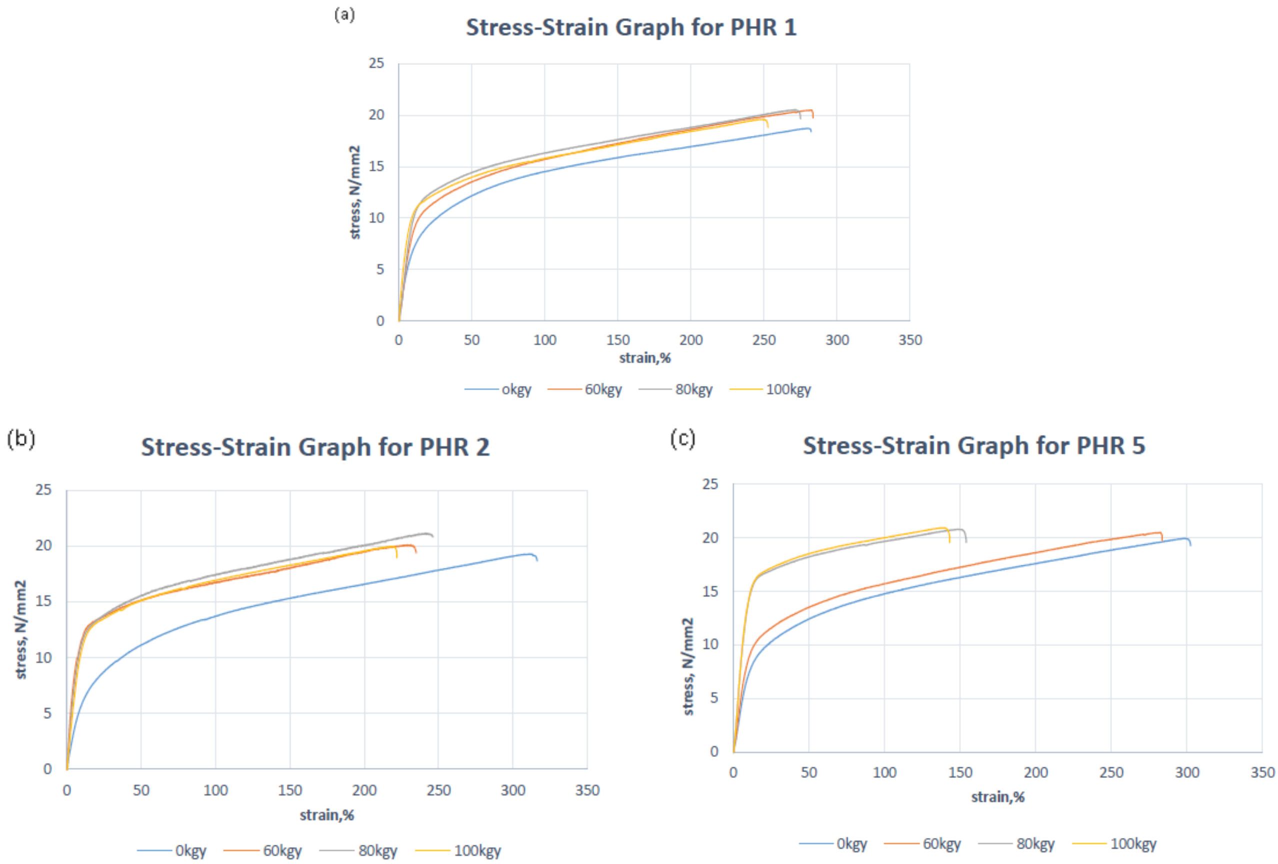

Fig. 13. Strain Graph for PHR 1, PHR 2 and PHR 5 (a) PHR 1, (b) PHR 2, (c) PHR 5

3.3 Conductivity Test

The mechanical properties observed in this experiment was the electrical conductivity that was measured by 16451B Dielectric Test Fixture and has been performed at room temperature (25°C). This testing was conducted to represent the amount of leakage current (space charge) that passes through the insulation materials.

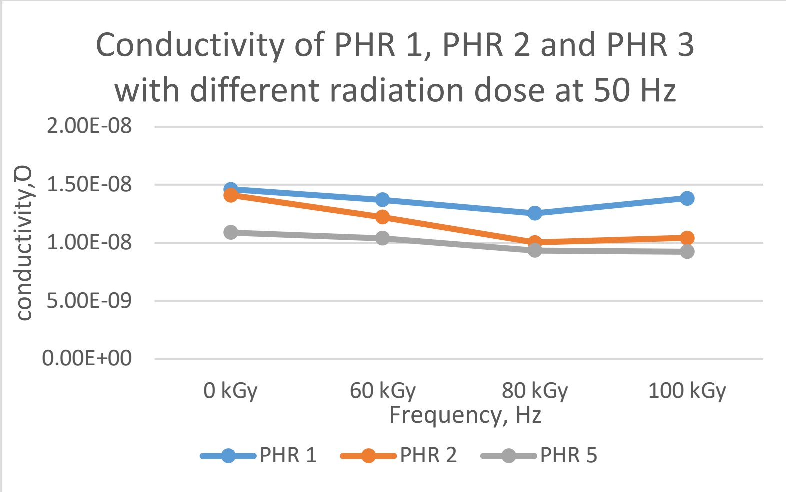

Fig. 14. Conductivity Graph for PHR 1, PHR 2 and PHR 3 with different dose at 50 Hz

The relationship between composition and radiation dose can be observed in Figure 14 where PHR 5 has the lowest conductivity even though it has not been irradiated yet because it contains more amount of additive which crosslink agent compound compared to PHR1 and PHR 2 that act as barriers for charge carrier transport and increase the resistance of the material. As the radiation dose increases, the conductivity also slightly decreases due to the crosslinking effect. For PHR 2, the conductivity was almost same with PHR 1 at 0 kGy (before irradiated) because there was no huge difference of composition between PHR 1 that can affect electrical conductivity. However, PHR 2 recorded higher crosslink formation compared to PHR 1 as shown at gel content test result. Thus, the conductivity of PHR 2 is lower than PHR 1 as the radiation doses increase.

The PHR (Parts per Hundred Resin) of a polymer can affect the behaviour of charge carriers in the material depending on the type and concentration of the additive used. Certain additives can decrease the number of charge carriers in the material and reduce its electrical conductivity. Besides, due to disordered arrangement of the polymer chains especially for amorphous material such as PVC, it will influence of the presence of localized states in a material. The presence of localized states can act as traps or barriers for the charge carriers, reducing their mobility and increasing the resistance of the material. Meanwhile, crosslinking affects the behaviour of charge carriers in material because of the formation of covalent bonds between polymer chains, which can affect the mobility of the polymer chains and the availability of charge carriers. In a crosslinked polymer, the polymer chains are linked together, forming a three-dimensional network structure that can restrict the mobility of the chains and impede the flow of charge carriers.

4. Conclusions

Observations indicate that variation of irradiation doses have an impact on the structural and mechanical characteristics of PVC. This demonstrates that a larger irradiation dosage does not always translate into greater strength and toughness. Electron beam irradiation does help in the crosslinking of PVC and boosted by TMPTA compound. This can be proved by the gel content test results that were obtained. It can be concluded that higher dose of irradiation has higher crosslinking but also depends on composition of PVC and TMPTA compound. This is because PHR 5 has the highest degree of gel content compared to PHR 1 and PHR 2 although same doses were exposed. It also determined that crosslinking improves the structure of PVC. For additional support of reliability of these conclusions it is necessary to do additional investigations. (1) To obtain direct evidence of binding of plasticizer molecules, IR-spectroscopy can be used. (2) To determine characteristics of network in absence of crystallites, swelling-methods can be used

Based on the tensile test result, PHR 5 has higher tensile stress compared to PHR 1 and PHR 2 at each dose. In the other hand, PHR 5 at 100 kGy recorded 21.1244 N/mm2 which the highest tensile strength at 100 kGy that 10.57% increase from the lowest tensile strength 18.8909 N/mm^2 recorded which is at PHR 1 0 kGy. The relationship between tensile strength and elongation at break is described as strength and ductility of the material. This relationship is due to the way in which the material deforms and fails under stress influenced by composition and radiation doses. It can be concluded that an increase in radiation dose and composition of TMPTA compound leads to increasing tensile strength but a decrease in elongation at break. It also found that increase in radiation dose and composition can make the material able to withstand higher stress load before experiencing plastic deformation. In other words, the material has higher yield modulus strength. The PVC samples contain a crystalline phase with a specific crystal structure. For XRD analysis, the diffraction peak was observed for all PHR values means that the crystalline phase is present throughout the material and is not affected by changes in the different concentration of additives.

For electrical properties, the conductivity was observed at 50 Hz because 50 Hz is a common frequency for the building electricity supply. The lowest conductivity was recorded by PHR 5 while PHR 1 was the highest conductivity. The conductivity factor is dominated by the behaviour of the charge carriers in the material that were influenced by radiation dose and the composition of the PVC. It can be proved at lower radiation doses (0 kGy and 60 kGy), crosslink has no significant effect thus PHR 5 have the lowest conductivity because of it has higher TMPTA compound that act as barriers for charge carrier transport and increase the resistance of the material. Meanwhile, as the higher radiation doses, (80 kGy and 100 kGy), the formation of crosslink chain becomes a crucial factor of the conductivity as it can restrict the mobility of the chains and impede the flow of charge carriers.

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