Applied Research and Smart Technology Vol. 2 No. 1 (2021) 1-7

ARS Tech

Applied Research and Smart Technology

Journal homepage: www.journals2.ums.ac.id/index.php/arstech ISSN 2722-9645

Research Article

Investigation of electrical treeing in perspex material

Mohammad Abderrazzaq[1,*]

[1]*Electrical Power Engineering Department, Yarmouk University, Irbid, Jordan.*

[*]Corresponding author: abder@yu.edu.jo

Permalink (DOI): https://doi.org/10.23917/arstech.v2i1.279

ARTICLE INFO

Article history:

Received 14 February 2021
Revised 08 March 2021
Accepted 26 March 2021
Available online 19 June 2021
Published regularly 30 June 2021

Keywords:

Deionised water
Electrical tree
Ionised water
Perspex material
Treeing photography

ABSTRACT

Perspex has been known for a long time as a polymeric material, and it has been used for a large number of electrical and non-electrical applications. The present work was carried out to investigate the ageing mechanism of perspex material under a high electric field. The electrical treeing phenomenon was studied using perspex samples with electrodes of a pin-to-plane configuration. The growth of an electrical tree in Perspex was measured and analysed with an advanced microscope equipped with a high-resolution camera and connected to a personal computer. Several distinct stages were assigned to characterise the electrical tree development. The area occupied by the electrical tree channels was calculated using equal-area squares. This approach was employed to measure the growth rate of electrical trees under dry and wet conditions. The tree construction, shape and growth speed were studied and analysed to distinguish between treeing phenomenon under wet and dry conditions of fabricated perspex specimens. Water absorption has increased the tree growth inside the samples, and ions with water have accelerated the breakdown process. The findings of this study are essential to improve the performance of perspex material, which is widely used in various applications for both energy and non-energy purposes.

1. INTRODUCTION

The application of strict social distancing requirements and the need for a cheap material to make a physical barrier between adjacent persons have led to an exponential increase in the use of Perspex in parallel with the spread of Covid-19 and the attempts to contain it [1]. Perspex is sometimes called plexiglass, acrylic glass or polymethyl methacrylate (PMMA). It is a homopolymer compound formed from methyl methacrylate compound's addition polymerisation reaction. This transparent plastic material is thermoplastic, stiff, rigid, and durable. It is widely used for several applications, including rear-light and instrument groups of vehicles, appliances and lenses of glasses. It has good tensile and flexural strength. Table 1 illustrates detailed information on the chemical composition and physical properties of the Perspex round bar.

Table 1. The physical properties and chemical composition of Perspex [2].

Properties	Composition/Values
Chemical Formula	$(C_5O_2H_2)_n$
Melting Point	160 °C
Boiling Point	200 °C
Density	1180 kg/m^3

Perspex is available in cast sheets with a surface roughness of 3 x 10^{-5} cm or less [2]. In glass transition temperature, it is also similar to too many polymers such as polyester. Perspex is resistant to outdoor environments, including ultraviolet radiation [3]. Therefore, acrylic moulding and extrusion compounds are frequently used in applications requiring retaining extreme clarity under severe weathering and other environmental exposures. This property has enabled Perspex to replace glass in all applications where temperatures below 90°C and low chemical resistance are required. Electrically, this material possesses excellent properties, including low electrical conductivity. However, the dielectric property of this material is not very high compared with polyethene, cross-linked polyethene (XLPE) and polyvinyl chloride (PVC). Therefore, cast sheets of Perspex are mainly used for distribution boards and lighting accessories.

A number of works [4,5] have been conducted to investigate the mechanical properties of Perspex and study its dielectric response to an electric field, whereas the detailed studies focusing on treeing process are relatively limited. Treeing is a pre-breakdown phenomenon occurring in dielectric material when it is subjected to a high electric field. It is mainly originated at points where mechanical defects or conducting impurities or protrusions exist. This phenomenon is associated with electrical discharges inside the material, cracks, and the weakening of such material's mechanical and electrical performance. Therefore, several studies have concentrated on the treeing analysis associated with discharge luminous image, fractal dimensions and discharge magnitude in each phase angle area [6-8]. Other works have focused on breakdown mechanisms and tree measurement using impulse voltages at different rise times [9,10]. A recent study has studied the effect of AC and DC voltages on power trees in low-density polyethene [11]. On the other hand, an experiment was carried out to characterise the directly grounding tree in Perspex located at the end of a coaxial cable [12].

The present work attempts to study the treeing process in Perspex using power frequency AC voltage. Several sets of identical samples were tested for dry and wet conditions. The tree growth and the time to break down were measured regularly. The tree's shape, dimension and construction were investigated using a microscopic system. The obtained images were photographed using a high-resolution camera mounted on a microscope with a high magnification factor. Finally, the microscope was connected to a personal computer, as shown in Figure 1.

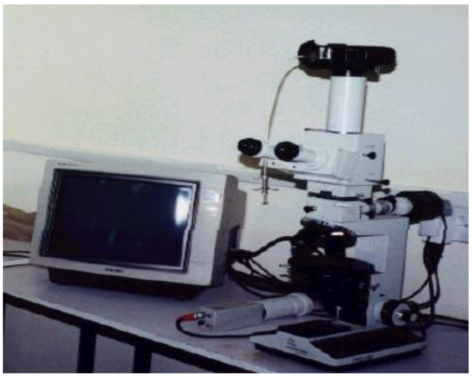

Figure 1. Treeing photography system.

2. MATERIALS AND METHOD

New Perspex material was obtained in large solid sheets of 50 cm x 50 cm x 0.6 cm [length x width x thickness]. A sufficient number of slabs were cut, each measuring 5 cm by 5 cm by 0.6 cm. A 0.5 mm-tip needle was inserted into the specimen to create a pin-to-plane configuration. The grounding lead was connected to the sample via aluminium foil facing the needle tip at a 1mm distance, as shown in Figure 2. This arrangement facilitated the test repetition and reduced the experiment time. The tests were performed in a clean area under controlled conditions. The temperature was 22±3°C, and the relative humidity was 35±5%. In the experiments, a fully controlled 25 kV testing transformer was used to test the specimens under various conditions.

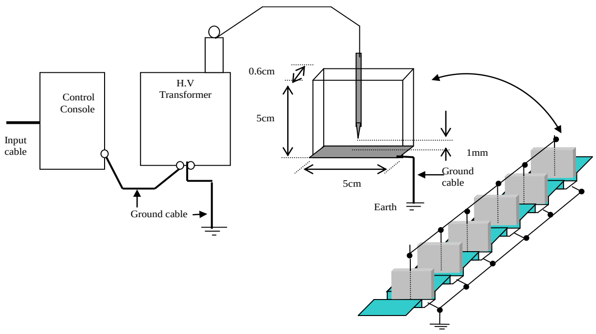

Figure 2. Sample configuration and test setup.

Before the test, Perspex samples were divided into three equal groups; dry, wet with distilled water and wet with ionised water. Groups of wet samples were initially allowed to absorb water for one week (168h) before being exposed to a high-voltage test. The samples were then exposed to an AC voltage of 11 kV (RMS) for regular intervals (1 hour).

3. RESULTS

The transparent characteristics of Perspex have been used to detect and trace the trees in the examined specimens. It was found that the tree branches grow in vertical and horizontal directions towards the earth electrode. The description of growth stages is achieved by systematically recording the tree expansion.

3.1. Dry samples

The horizontal (along X-axis) and vertical (along Y-axis) channels were measured at equal intervals to specify the tree development in dry Perspex specimens. The horizontal component of the tree consists of all horizontal extensions of the branches on both sides of the main direction of the tree, whereas the vertical part considers only the straight-up expansions directed towards the earth electrode.

Figure 3 demonstrates the growth process from the moment of tree initiation to the breakdown. For most of the tree life, the horizontal growth is slightly higher than that of the vertical one. However, just before the breakdown occurs, the vertical growth remarkably increases above the horizontal component.

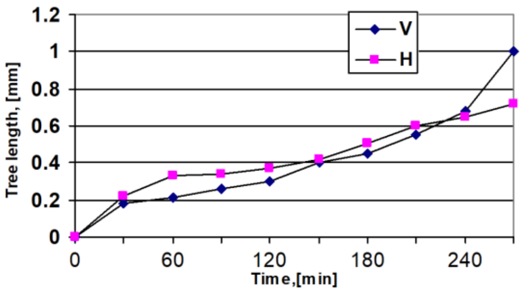

Figure 3. Vertical and horizontal tree growth for dry Perspex samples.

Three distinct stages are considered by comparing the tree growth in the horizontal and vertical directions. The primary stage characterises the first hour of tree development. In this phase, the horizontal growth is higher than the vertical one. The vertical change is significant in the second stage, compared with the horizontal one increasing at a constant rate. The third stage starts when the tree front approaches the earth electrode.

Although the total horizontal growth is higher than that of the vertical one, the latter is more effective in causing breakdown. However, not all horizontal channels grow in the same direction, but many abruptly go to the earth electrode. Therefore, the insulation area surrounded by the horizontal and vertical channels is considered. It is achieved by dividing the space between the pin tip and the earth plate into treed and non-treed sections. The treed section, enclosed by the outer branches, includes the tree itself, whereas the remaining space outside the tree frame is the non-treed area. Figure 4 shows samples of trees depicted at a magnification of 300 times.

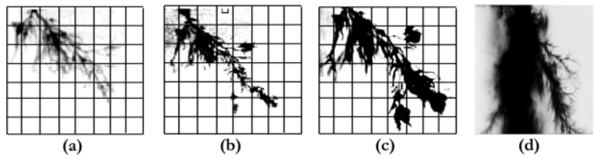

Figure 4. Tree growth in dry Perspex. (a) after 1 hour, (b) after 2 hours, (c) after 3 hours, (d) breakdown stage.

As in Figure 4, the images overlaid on a grid of squares describe the stages of tree development. The squares containing branches determine the effective area of the tree. However, the site shown in the above figure does not include the total width of the sample, which is far more significant (50 mm) than the vertical distance between the pin and earth electrodes (1mm). By counting the increment of tree-contained squares, it is possible to measure the growth progress and the actual area of the tree. The time variation of the treed area for dry samples is shown in Figure 5, whereas, Figure 6 illustrates the change in the actual location of the tree, expressed as a percentage of the treed section. The entire tree area consists of only a tiny portion of the total insulation between the pin and earth electrodes.

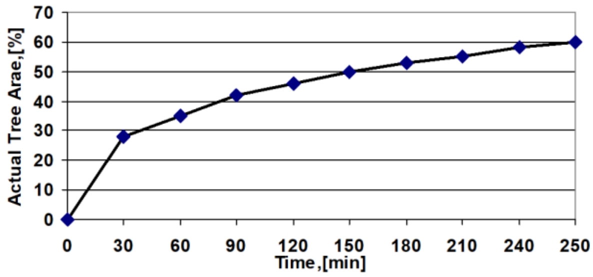

Figure 5. Variation of treed area related to the space between pin and ground electrodes.

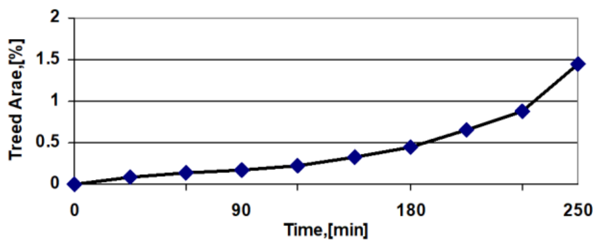

Figure 6. Variation of actual tree area related to the treed area.

The branches of a dry tree are short and thick. Initially, they have a brown colour, turning black in the final growth stage. Moreover, the horizontal and vertical tree expansions are relatively slow and limited within a narrow zone of treed section. However, they move perpendicularly towards the earth electrode at a constant rate.

3.2. Wet samples with deionised water

In the study, the samples were exposed to distilled water for one week before being subjected to a high-voltage supply. During this time, a sufficient quantity of water is absorbed and distributed inside the examined sample. The results have shown that active growth occurs in horizontal and vertical directions. However, the tree elongation in the vertical direction is lower than that in the horizontal one. The difference between the two components remained constant throughout the whole life of the tree, as shown in Figure 7.

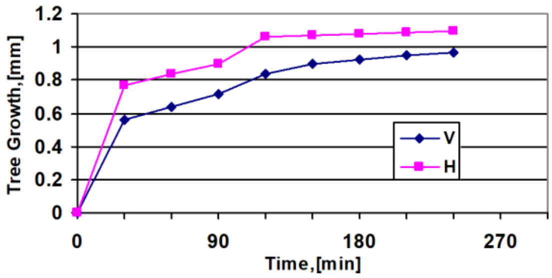

Figure 7. Vertical and horizontal tree growth for wet Perspex.

Due to the intensive and fast distribution of the tree, it was not easy to contain all branches in a single image. Therefore, to obtain a complete picture, it was necessary to employ the computer facilities to integrate all images of the channels, growing in various directions, into a single tree shape, as shown in Figure 8. Compared with a dry case, the wet tree occupies a broader area with different routes followed by thin, long and sparse channels. The obtained results of free growth agree with the findings of other researchers [13,14], who considered that the presence of water in the polymer would decrease the material's mechanical strength and, consequently, reduce the growth resistance, making the tree extension much more straightforward.

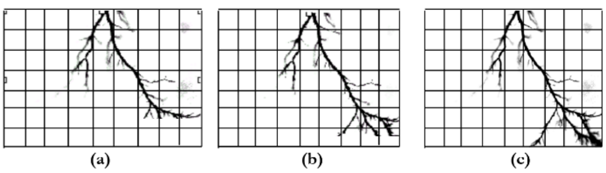

Figure 8. Stages of tree growth depicted in wet Perspex samples absorbing distilled water. (a) after 1 hour. (b) after 2 hours. (c) after 3 hours.

Figure 9 shows the time variation of a treed section, whereas, Figure 10 illustrates the percentage change of the actual tree area. In both illustrations, the increase in the treed and existing tree areas is much higher than that of the dry test shown in Figures 5 and 6, respectively. Nevertheless, expanding the above parameters in the first hour of tree growth is considerably higher than in the subsequent hours of tree life.

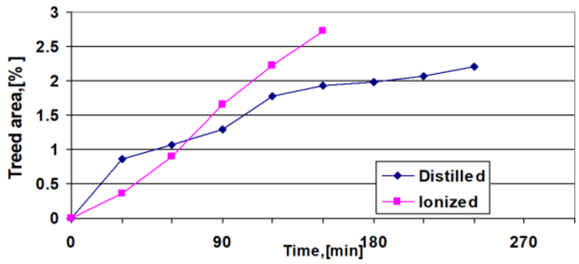

Figure 9. Variation of wet treed area related to the total pin-to-ground space.

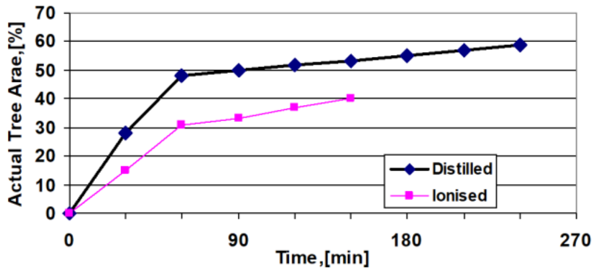

Figure 10. Variation of actual tree area related to the treed section.

3.3. Wet samples with ionised water

The presence of ions in absorbed water accelerates the breakdown due to the conduction activity of these ions [15-19]. This fact is clearly found here. The tree initiation and development processes are significantly faster than those obtained in the previous cases. The total time to breakdown for the samples absorbed ionised water was 164 min compared with 250 and 280 min for wet (distilled water) and dry cases, respectively. Additionally, the total horizontal growth was higher than in other cases, as shown in Figure 11.

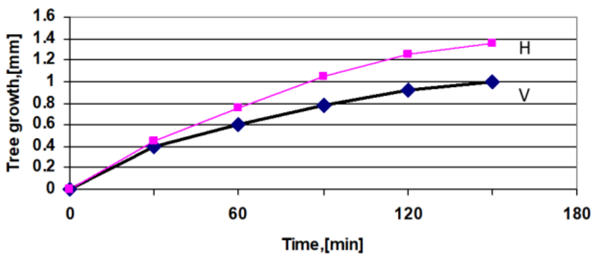

Figure 11. Vertical and horizontal tree growth for Perspex samples exposed to ionised water.

The extension occurs in all directions with fine and interlaced channels regarding the tree structure and shape, as shown in Figure 12. The fast growth of a tree in this condition causes an enlargement in the treed section. Furthermore, it influences an increase in the ratio of the treed neighbourhood to the total area between the pin and earth electrodes. The ionised water curve in Figure 9 shows the variation of the above ratio presented in a percentage form, whereas the ionised water curve in Figure 10 illustrates the percentage variation of the actual tree area concerning the entire treed section. Despite the notable ability of this type of tree to enclose a wide area during the growing process, the real tree space is less than that obtained for distilled water and dry cases due to the limited number and thickness of grown branches.

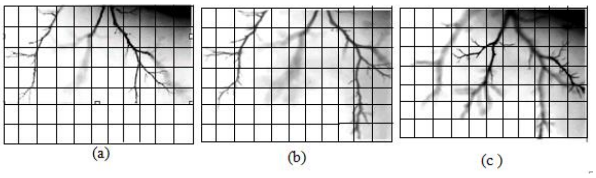

Figure 12. Stages of tree growth in wet Perspex specimens using ionised water. (a) after 30 minutes. (b) after 70 minutes. (c) after 120 minutes.

4. DISCUSSION

A number of findings can be discussed concerning tree growth and configuration. Firstly, the growth rate in similar samples is slightly different due to minor variations in the material structure, and it can be attributed to impurities and the non-uniform distribution of these impurities inside the material. Secondly, the tree growth in wet specimens is higher than in dry ones. The tree area contains various voids stressed by electrostriction forces associated with a high electric field. With the increase in absorbed water, these stresses are magnified, causing more influence on the tree propagation. Finally, the time to break down is a function of the condition of the specimen. Therefore, the longest breakdown is associated with dry samples, followed by wet (deionised) and ionised samples.

The results have shown that the tree shape and construction are affected by the growth mode concerning the configuration. In dry specimens, the tree developed slowly and did not have the chance to spread widely inside the sample. Therefore, the treed section is small, and the branches are concentrated around one primary channel. Thus, such a tree is compressed and compact. Then, these channels are gradually enlarged and darkened, which refers to internal material damage. A breakdown is initiated if one of the front branches approaches the earth electrode. Therefore, the last treeing hour is associated with a significant increase in vertical growth compared to the horizontal one.

The electrical tree developed in wet (deionised) conditions is characterised by long, thin and fast-growing branches. Although the main direction of these branches is from the pin tip to the earth plane, many channels are randomly distributed in all directions, including the horizontal direction. The vertical and horizontal frames of the tree have dictated the ratio of the treed region to the whole insulation area. However, the density of branches in the treed region determines the actual site of the tree. The treed neighbourhood, in this case, has grown more extensive than the dry one, while the ratio of the existing tree to the treed section has remained constant in both cases. It is attributed to the fact that the tree density and dimensions are proportionally increased. Despite the remarkable growth in the horizontal direction of wet samples, the fast vertical growth is the leading cause of the early breakdown of these samples compared to the dry ones.

The trees in the specimens treated with ionised water are characterised by fast growth and a high density of branches. Therefore, the treed region is significantly more extensive than the dry and distilled water cases. However, the limited number of branches has decreased the tree's actual area, making it smaller than in other cases.

The tree branches behave like conductors in all studied cases, bridging the distance between the electrodes and causing the insulation to break down. With ionised water, the breakdown occurred earlier than in other cases, revealing the role of ions in increasing water absorption and breakdown under a high field. It agrees with the results obtained previously [20].

Finally, random growth is the ordinary course of action, which the electrical trees have demonstrated in the various studied cases. It means that in most cases, the tree has not linearly grown with time. Therefore, it is customary to note that a lateral branch can be initiated from an existing tree stem or growing branch, and this newly developed branch could be in a horizontal or vertical direction.

5. CONCLUSION

Electrical tree initiation and growth have been investigated for Perspex material under different conditions. The presence of micro-voids during the manufacturing process of Perspex has caused sustained partial discharges under the applied electrical field. Apart from the difference in permittivity between the air inside the voids and the surrounding Perspex, the field in the voids has been enhanced, and the tree has begun to grow.

The effect of water in changing the permittivity of the Perspex is reflected in the treeing mode. Therefore, the insulation area between the electrodes is divided into treed and non-treed sections. The dimensions of the treed neighbourhood are governed by the outer extensions of the tree, whereas the density of branches determines the actual tree area. The adopted approach to investigate tree growth is based on tree elongations in horizontal and vertical directions under dry and wet conditions. The study of the relationship between water absorption and the treeing process is not limited to the growth but extends to include the tree shape and texture.

Finally, the results of this paper would be of great importance for researchers in Perspex material, especially with the significant growth of the current use of such material. The massive increase in orders of Perspex and the need to conduct studies on such material to make safe barriers to reduce exposure to COVID-19 reflect that interest.

CONFLICTS OF INTEREST

The author declares that there is no conflict of interest affecting this publication.

ACKNOWLEDGEMENT

The author would like to thank Yarmouk University for supporting the research.

REFERENCES

[1] A. Eykelbosh, "Physical barriers for COVID-19 infection and control in commercial setting", *Article in National Collaborating Centre for Environmental Health*, May 13, 2020. https://ncceh.ca/content/blog/physical-barriers-covid-19-infection-prevention-and-control-commercial-settings

[2] I.P. Okokpujie, E.Y. Salawu, O.N. Nwoke, U.C. Okonkwo, I.O. Ohijeagbon, and K.O. Okokpujie, "Effects of process parameters on vibration frequency in turning operations of perspex material", *Proceedings of the World Congress on Engineering*, pp. 700-707, 2018. http://eprints.covenantuniversity.edu.ng/id/eprint/11183

[3] S.S. Sackey, M.K. Vowotor, A. Owusu, P. Mensah-Amoah, E.T. Tatchie, B. Sefa-Ntiri, C.O. Hood and S. Atiemo, "Spectroscopic study of UV transparency of some materials", *Environment and Pollution*, Vol. 4, No. 1; 2015. https://doi.org/10.5539/ep.v4n4p1

[4] H. Kamikubo, K. Urano, Y. Ehara, and T. Ito, "Analysis of electrical treeing process by discharge luminous image and discharge magnitude in each phase angle area", *The 7th International Conference on Dielectric Materials, Measurements and Applications (Conference Publication No. 430)*, pp. 326-329, 1996. https://doi.org/10.1049/cp:19961051.

[5] M. Fujii, T. Saito, H. Ohnishi, K. Arii and K. Yoshino, "Three-dimensional measurement of tree in polymer applied successive impulse voltage and their multifractal", *Proceedings of the 5th International Conference on Conduction and Breakdown in Solid Dielectrics*, pp. 304-308, 1995. https://doi.org/10.1109/ICSD.1995.522998

[6] M. Naoe, Y. Ehara, H. Kishida, and T. Ito, "The fractal analysis of the treeing process", *Proceedings of Conference on Electrical Insulation and Dielectric Phenomena*, pp. 779-782. 1996. https://doi.org/10.1109/CEIDP.1996.564624.

[7] J.C. Fothergill, "Ageing, space charge and nanodielectrics: ten things we don't know about dielectrics", *Proceedings of 2007 IEEE International Conference on Solid Dielectrics*, pp. 1–10, 2007. http://dx.doi.org/10.1109/ICSD.2007.4290739

[8] Y. Fan, D. Zhang, and J. Li, "Study on the fractal dimension and growth time of electrical treeing degradation at different temperature and moisture", Hindawi, *Advances in Materials Science and Engineering*, Volume 2018, Article ID 6019269, 10 pages, http://doi.org/10.1155/2018/6019269.

[9] D.W. Auckland, L.A. Renforth and B.R. Varlow, "The effect of space charge on the fracture toughness of Perspex", *Sixth International Conference on Dielectric Materials, Measurements and Applications*, Pub. No. 363, INSPEC Accession Number 4281416, pp. 209-212, 1992.

[10] J. James and S.V. Kulkarni, "Detection of electrical tree propagation in Perspex by partial discharge measurements", *3rd International Conference on Condition Assessment Techniques in Electrical Systems (CATCON)*, pp. 222-225, 2017. https://doi.org/10.1109/CATCON.2017.8280216.

[11] H. Zheng, G. Chen and S.M. Rowland, "The influence of AC and DC voltages on electrical treeing in low density polyethylene", *International Journal of Electrical Power and Energy Systems*, Vol.*114*, 105386, 2020. https://doi.org/10.1016/j.ijepes.2019.105386

[12] I. Kitani, Y. Sasaki, T. Fukui and K. Arii, "Directly grounding tree in PMMA located at the end of a coaxial cable", *Proceedings of IEEE 5th International Conference on Conduction and Breakdown in Solid Dielectrics*, pp. 523-527, 1995. https://doi.org/10.1109/ICSD.1995.523041

[13] R.J. Young, "Introduction to polymers", Champion and Hall, 4th edition, London. 1987.

[14] D.W. Auckland and B.R. Varlow, "Dependence of electrical tree inception and growth on mechanical properties", *Proceedings of the 3rd International Conference on Conduction and Breakdown in Solid Dielectrics*, 1989, pp. 533-537, 1989. https://doi.org/10.1109/ICSD.1989.69254

[15] M.D.R. Teixeira, "New MV cable design for wet environments in underground distribution systems", *IEEE Transaction on Power Delivery*, Vol. 5, No. 2, pp 787-792, 1990. https://doi.org/10.1109/61.53084

[16] M. Danikas, D. Papadopoulos and S. Morsalin, '"Propagation of Electrical trees under the influence of mechanical stresses: a short review", engineering, *Technology and Applied Science Research*, Vol. 9, No.1, pp. 3750-3756. 2019. https://doi.org/10.48/etasr.2483

[17] M.I. Qureshi, A.A. Al-Ahaideb, A.A. Al-Arainy, and N.M. Malik, "Role of semiconducting screens on water treeing in medium voltage XLPE Cables", *Journal of King Saud University-Engineering Science*, Vol. 17, No. 2, pp. 227-242, 2005. https://doi.org/10.1016/S1018-3639(18)30809-2

[18] A. El-Zein, Kh. Mohamed, and M. Talaat, "Water trees in polyethylene insulated power cables: Approach to water trees initiated mechanism", *Electrical Power System Research*, Vol. 180, March 2020, 106158. https://doi.org/10.106/j.epsr.2019.106158

[19] M. Abderrazzaq, D.W. Auckland and B.R. Varlow, "Effect of water absorption on the growth of water trees in composite insulation", *Proceedings of Conference on Electrical Insulation and Dielectric Phenomena*, Vol. 2, pp. 766-769, 1996. https://doi.org/10.1109/CEIDP.1996.564621

[20] M. Abderrazzaq, D.W. Auckland and B.R. Varlow, "Investigation of the factors governing water absorption in HV composite insulation", *IEEE Trans. Dielectrics and Electrical Insulation*, Vol. 5, No. 6, pp. 922-928, 1998. https://doi.org/10.1109/94.740777