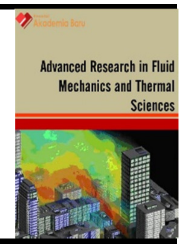
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Assessing and Quality Tests of New PVC Electrical Cables Outer Sheath by Accelerated Thermal Ageing

Open Access

M'hamed Beriache[1,*], Djelloul Saïh Merzouk[2], Nor Azwadi Che Sidik[3]

[1] Laboratory of Rheology and Mechanics, Department of Mechanical Engineering, Faculty of Technology, Hassiba Benbouali University of Chlef, B.P 78C, Ouled Fares Chlef 02180, Algeria
[2] Department of Mechanical Engineering, Faculty of Technology, Hassiba Benbouali University of Chlef, B.P 78C, Ouled Fares Chlef 02180, Algeria
[3] Malaysia–Japan International Institute of Technology (MJIIT), University Teknologi Malaysia Kuala Lumpur, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 7 January 2018
Received in revised form 14 March 2018
Accepted 24 March 2018
Available online 19 April 2018

Keywords:
Poly (vinyl chloride), PVC, cables, outer sheath, ageing, insulation, breakdown

ABSTRACT

In Algeria, XLPE and PVC are the most widely used materials in cable insulation industries. The severe climate conditions in Algeria, plus tremendous factors in stressing cables insulations and shorten their lifetime. This study presents results of a tested material (PVC ST2 IRIS) on medium and low voltage cable outer sheath using different experimental techniques, especially; elongation at break (EAB), hot stretching test, Thermal shock test and weight loss method and the thermo-mechanical properties to determine how valid and safe are the proposed outer sheath materials used in cables manufacturing. The obtained results show that, the mechanical properties after accelerated thermal aging are affected by less than 9% with those before aging. These results are conformed to the standard CEI recommendations. The findings of the present experimental work show that the new tested (PVC ST2 IRIS) material passed all the approval mechanical tests successfully, and has approved to be marketed and operated in practice.

1. Introduction

Power transmission cables generally consist of conductor core surrounded by multiple insulation layers. For protection against mechanical damage and environment contact, sheathing is extruded around one or more of the insulated conductor wires. Polyethylene (PE) and Polyvinylchloride (PVC) are the most used materials in the wire and cable industry. They provide insulation and outer sheathing for more than 30000 different types of wire and cable products [1]. In view of their various applications, polymeric materials play an essential role in the insulation of electrical cables for its extremely good properties such as electrical, mechanical and thermal

[*] *Corresponding author.*
E-mail address: m.beriache@gmail.com (M'hamed Beriache)

characteristics. The reliability of these is mainly determined by the sustainability of the insulation properties [2].

Electrical cables failures are often related with dielectric breakdown phenomena insulators. These phenomena can occur for electric fields well below the break down fields to materials [3]. This performance drop is mainly attributed to many factors act more or less directly affect the lifespan of organic insulators. Commonly divided internal aging external aging of these materials. Internal aging is linked primarily to the instability of thermodynamic states of the polymer material. External aging phenomena have very different origins. Electrical treeing is considered the most relevant mechanism of insulation breakdown in different solid insulating materials. We can identify not only constraints of conventional electric type, thermal or mechanical, but also more difficult to identify such as moisture stress, abnormal presence of a type of molecule (impurities), bubbles, gas void, mechanical cracks and effect of radiation [4]. The prediction of a dielectric breakdown remains difficult to be done if we are to take into account all the parameters involved in the phenomenon of aging. A large number of phenomena has been implicated in the process of damage organic insulating and different approaches have been presented [5]. According to the particular properties of polymer materials.

In literature, several works dealing degradation outer sheath of electrical cables. It is seen that most of the cable insulations are manufactured with great care so that no impurity is added or remain in the insulation. Nevertheless, some small amount of impurity is always present during its manufacturing process. The impurities are appearing in the form of solid, liquid or gas. During the time of manufacturing process of such cable insulation, the impurity is present in the form of air bubble and voids which creates a weak field inside the insulation. Most of the failure of such insulation occurs due to presence of partial discharge at the weak zones with high voltage stress in the polymeric cable insulation. In the recent years, Zaikov *et al*., [6] pointed out that loss of plasticizer causes formation of voids in the material and, as discussed above, formation of voids will reduce the breakdown strength of the insulation. Nadjar *et al*., [7] studied the thermal aging of poly (vinyl chloride) (PVC) used in medium and high-voltage cables. They showed that the thermal aging leads to the degradation of the material and to the modification of its electrical properties. The degradation is all the more important and faster as the temperature is high. Pinkorova and Polinsky [8] have analysed thermal and mechanical properties of two cable insulations for operation under specific conditions. It was determined, that a net change of sheath materials properties is coming in the temperature range (60-100°C), which corresponding with the beginning of melting.

The purpose of the present work is the characterization of low and medium voltage cable new PVC outer sheath in an effort to assess and approve it in aim to be marketed and operated in practice. PVC ST2 material assessment and quality tests were carried out according to the standard CEI 60 502-2 (2014) [9].

2. Experimentation

2.1 Materials and Sample Preparation

In this work, the PVC ST2 virgin formulation low and medium voltage electrical insulation cable was studied. PVC coming from the outer sheath of single core cable (1X120mm² Al/XLPE/PVC-18/30KV) used by SONELGAZ (National Company of Electricity and Gaz), (Figure 1).

Mechanical properties were measured by using universal testing machine Instron4301 (Fig. 2). The samples were dumbbell-shaped (Fig. 3.) and were measured according to the Standard *EN 50363-0 (2011)* [10] at ambient temperature and different other temperatures. For each test, the measurements on the samples are made five times according to [11]. The specimen was placed in the machine between the grips and an extensometer can automatically record the change in gauge length during the test. The measures are down at *23 °C* and *50%* of relative humidity.

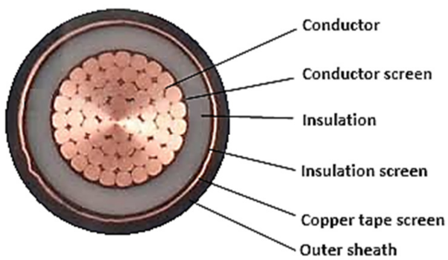


Fig. 1. Single core cable outer sheathed with PVC

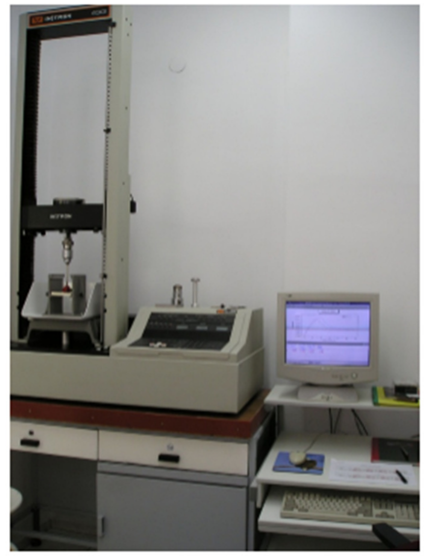


Fig. 2. Universal testing machine Instron4301

When the machine is turned on, it begins to exert an increasing load on specimen. During the tests, the control system and its associated software record the load and elongation of the specimen. For this analysis, the load and the extension of specimen were recorded. From the measured data, the tensile strength and elongation at break were then calculated.

2.2. Sampling and Materials

The outer sheath material of the cable used in this study is a Polyvinylchloride material, typically referred to as PVC ST2. This material has the registered trade name of ST2 and is produced by the IRIS Company. After obtaining plates of *12.9 cm* in diameter and (*2 ± 0.2*) *mm* thick, we cut dumbbells specimens for mechanical testing and mass loss (Figure 3) in accordance with *IEC 540* [12].

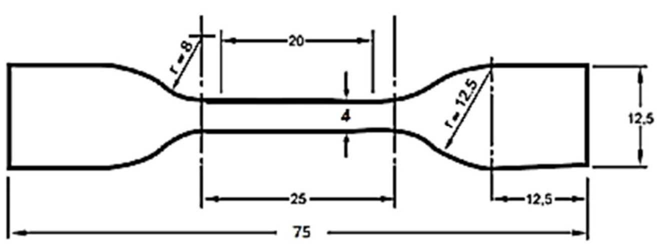


Fig. 3. Dumbbell-shaped sample

3. Results and Discussions

When the aging treatment is performed on the prepared samples (in accordance with IEC 608 116 401) [13], the test specimen for aging must be taken adjacent to specimens used for testing without aging, and tensile tests on samples aged and unaged should be performed immediately following. Before starting the test, the cross section of the sample to be stretched is first measured. Then we draw two remote markers *20 mm* on the narrow part of the specimen. Indeed, break occurs in this part. The test will be to submit the specimen in tensile, a constant adjustment speed until it breaks. It is noted firstly the breaking load indicated by the apparatus and the other measuring the elongation at break [14]. In the present experimental work, for each test five specimens are tested for more results insurance.

3.1 Measurement Techniques for Mechanical Properties

The most common measurement for sensitivity to aged conditions is destructive tensile testing known as elongation at break. Tensile strength may increase during aging and then dramatically decrease with some insulators. However useful in research, it is not practical to destructively test in-use cables for determining their aged condition [15]. Tensile testing has historically been used in the cable industry to evaluate the thermal aging behavior of cables with the primary focus on ultimate tensile elongation, also known as elongation at break (EAB). The EAB is used as a preferred reference metric because it decreases directly with age, while quantities such as tensile strength may increase with age and then start decreasing.

3.2 Tensile Testing

The tensile strength is the ratio of the breaking load by the cross section of the specimen (Eq. 1), as that R_T represents the tensile strength (*N/mm²*), F_T is the tensile force (*N*), and S is the cross section of the specimen (mm²).

$$R_T = \frac{F_T}{S} \tag{1}$$

Before aging, the value of the tensile strength was 16.5 *N/mm²* (Fig. 4). This result is consistent with the recommendations of *IEC 60502* [15], which requires a minimum value of 12.5 *N/mm²*.

3.3 Measurement of Elongation at Break (EAB)

The elongation at break is expressed in [%], is given by the relation (2), such that L_0 represents the length initial strokes between the two marks before specimen break (mm) and *L* is the length between both marks after break of the test specimen (*mm*).

$$A[\%] = \frac{(L-L_0).100}{L_0} \tag{2}$$

As for the tensile strength, we have checked the condition imposed by *IEC 60502* [16]. This standard sets the minimum value of the elongation at break before aging *200%*. Indeed, we found 485.87 *%* (Figure 4).

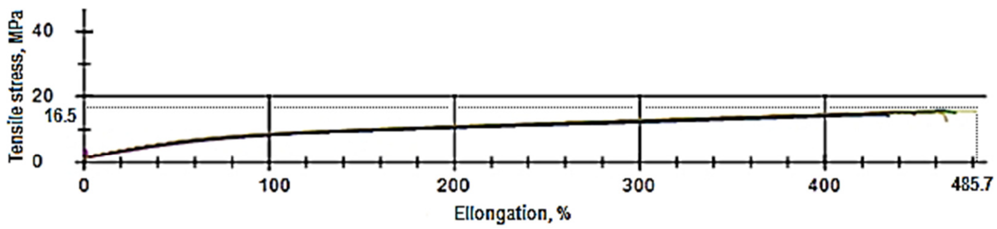


Fig. 4. Tensile curve of the material at break without aging

3.4 Determination of the Mechanical Properties of the Insulating Sheath Before and After Aging

Tensile testing has historically been used in the cable industry to evaluate the thermal aging behavior of cables with the primary focus on ultimate tensile elongation, also known as elongation at break (EAB) [17]. The EAB is used as a preferred reference metric because it decreases directly with age, while quantities such as tensile strength may increase with age and then start decreasing.

3.4.1 Test without aging at 100 °C

The results of this test are shown in Figs. 5 and 6. According to these figures, the elongation at break and the corresponding tensile stress before aging (Fig. 5) are better than those obtained after aging at 100 ° C for a week (Fig.6). The aging influence rates on the properties of the material are respectively 7.69% and 8.44% for the elongation at break and the tensile stress (Tables 1 and 2). These results are in good compliance with those prescribed (Tables 1 and 2).

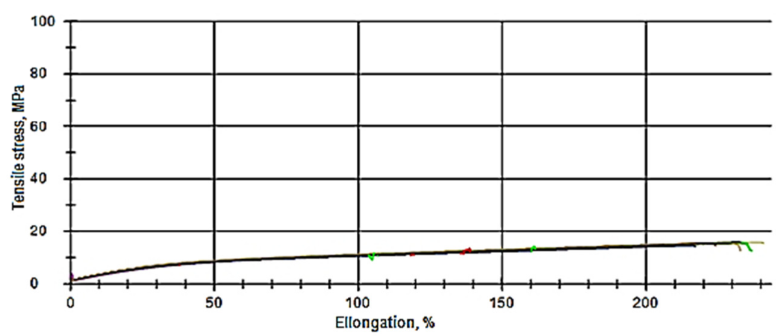


Fig. 5. Resistance strength versus elongation at break (without aging)

3.4.2 Test with aging during 7 days at 100 ±2 °C

Figure 6 represents the tensile stress in [MPa] versus the elongation after application of the thermal aging for 7 days at 100+ 2 °C.

The results obtained in the previous test are grouped in Tables 1 and 2 below, compared and validated with those recommended by IEC 60502.

Table 1
Tensile strength and elongation without aging

Designation of tests	Unit	Prescribed	Measured	Conformity
Tensile strength	N/m²	≥ 12.5	**15,4**	Conform
Elongation at break	%	≥ 200	**228.7**	Conform
Maximum variation	%	±25	**-7.69**	conform

Table 2
Tensile strength and elongation after aging

Designation of tests	Unit	Prescribed	Measured	Conformity
Tensile strength	N/m²	≥ 11.5	**14,3**	Conform
Elongation at break	%	≥ 150	**179.9**	Conform
Maximum variation	%	±25	**-8.44**	conform

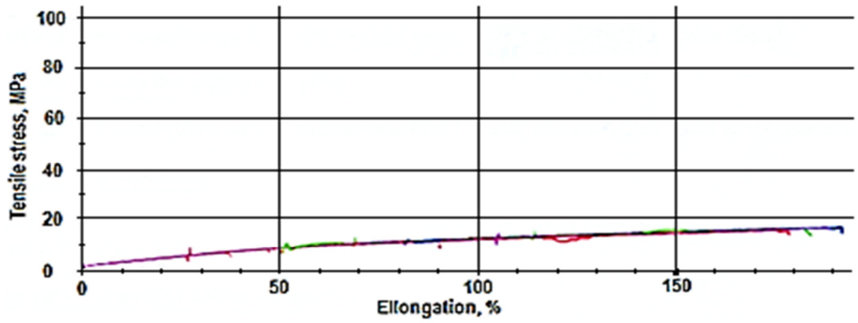


Fig. 6. Elongation resistance after aging

3.4.3 Aging tests on whole cable segment 7 days at 100 ± 2 °C
3.4.3.1 Test without aging at 100 °C

The results of this test are shown in Figs. 7 and 8. According to fig. 9. The results obtained for our tested material are much better than those prescribed by IEC before and after thermal aging. The influence of aging on the characteristics of the material for the present test is of the order of 4.43 % for the tensile stress and of 1.05 % for the elongation at break (EAB), which are very acceptable.

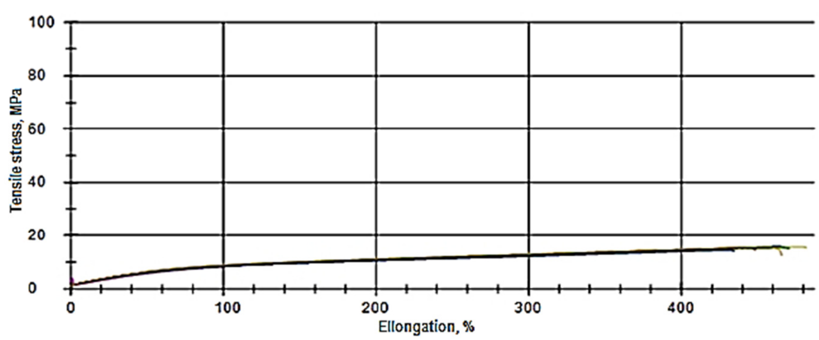


Fig. 7. Tensile curve at break (Without aging)

3.4.3.2 Test with aging at 100 °C

Fig. 6 represents the tensile stress in [MPa] as a function of the elongation on a whole cable segment after application of the thermal aging at 100 ± 2 °C for 7 days.

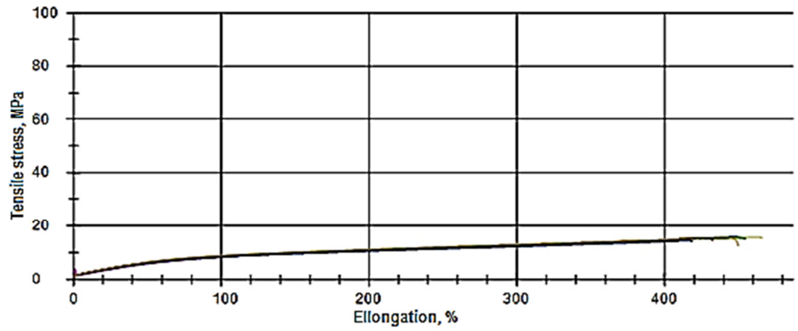


Fig. 8. Tensile curve at break (After aging)

The results obtained above are gathered, compared and validated in the Figure 9 as follow:

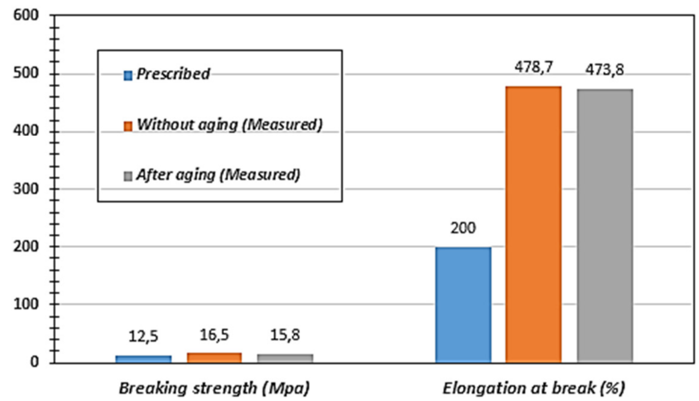


Fig. 9. Validation of results with those of IEC recommendations, (7 days @ 100 °C)

3.5 Additional Aging Tests on Whole Cable Segment 7 Days at 135 ± 2 ° C

3.5.1 Test without aging at 135 °C

The results of this test are shown in Figure 10. The tensile strength increases initially, then reaches a maximum, and decreases thereafter. The increase in tensile strength is attributed to the improved quality of the insulation due to the crosslinking.

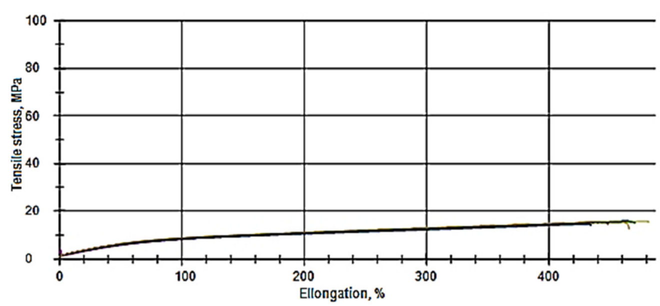


Fig. 10. Tensile curve at break (Without aging)

3.5.2 Test with aging at 135 °C

Figure 11 represents the results of the additional aging test on whole cable segment at 135 ± 2 °C during 7 days at 135 ± 2 °C.

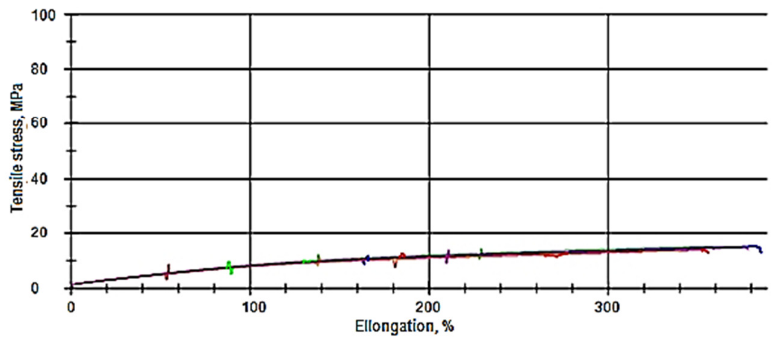


Fig. 11. Tensile curve at break (After aging)

Fig. 12 shows the comparison of test results before and after aging on whole cable segment during 7 days at 135 ± 2 °C and their validation with those prescribed by IEC.

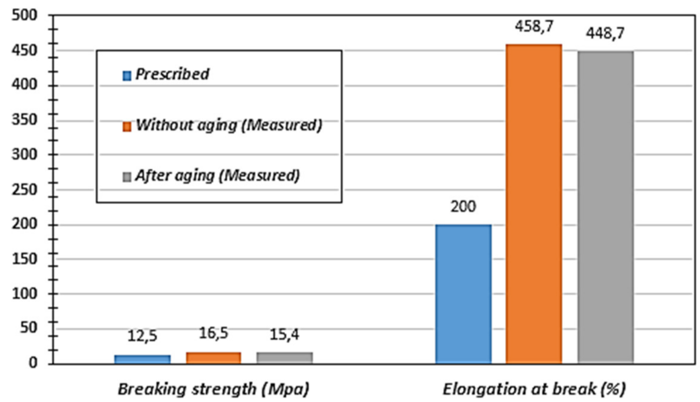


Fig. 12. Validation of results with those of IEC recommendations, (7 days @ 135 °C)

For all previous tests, after aging, we find that for all temperatures, the tensile strength increases initially and then reaches a maximum and decreases thereafter. The increase in tensile strength is attributed to the improved quality of the insulation due to the crosslinking. The decrease is even more rapid than aging temperature is higher (100 °C, 135 °C and 200 °C). After aging, the elongation at break (EAB), this characteristic was affected by 4.43 % after aging at 100 °C for 7 days (168 hour) and by 8.44 % after aging at 135 °C for 7 days.

For other temperatures 135 °C, and 200 °C, we see a decrease in that feature during aging which can be interpreted in a loss of material ductility. Note also that this decrease is even faster than the aging temperature is larger. As for the rapid decline of this characteristic, it is mainly due to cuts molecular chains [18, 19]. This phenomenon causes a decrease in the average molecular weight and reticulation rate of one hand and a loss of the other plasticizers. Indeed, the separation process channels increases mobility chains these results match with those suggested by 60811-509© CEI [19].

3.6 Hot Stretching Test on Insulating Sheath

The test specimens are subjected for *15* minutes at a temperature of *200 °C* under a tensile load of $F = 20\ N/cm^2$. The results obtained are shown in Figure 12.

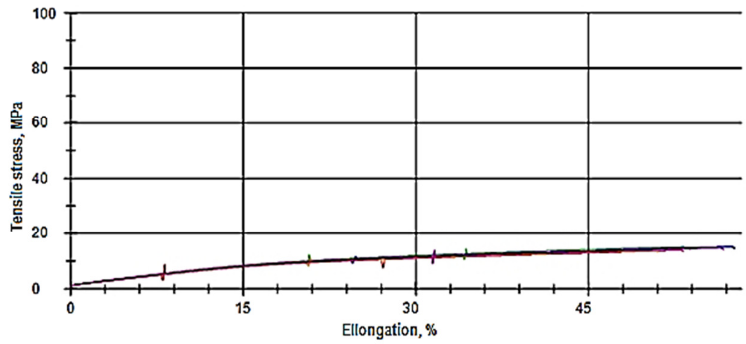


Fig. 12. Elongation test under load and hot

In this test, the load (20 MPa) is higher than that recorded on the material without aging (16.5 MPa) and the temperature (200 °C) is very high compared to those of previous tests. As a result, the mechanical properties of the material are quickly and significantly influenced. As a result, the elongation at break is considerably shortened compared to that before aging.

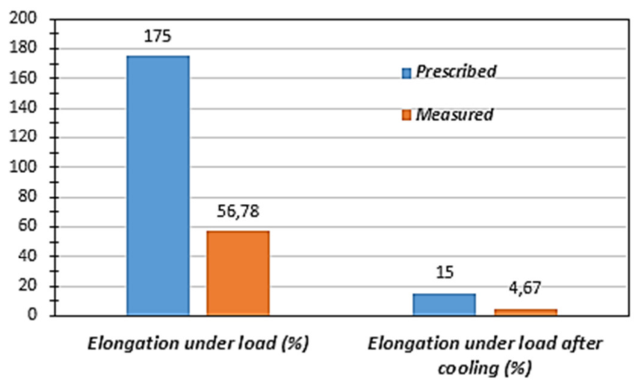


Fig. 13. Elongation test under load and hot results validated with prescribed values

3.7 Weight Loss Test

Weight difference is a measurement of change in a physical property to achieve thermal endurance characterization of the tested materials. Digital balance from Mettler Instrument model AE200, with accuracy ± 1×10^{-4} gram has been used to determine samples' weight before and after aging. The experiment may be performed under inert, reactive, or oxidizing atmosphere and the TGA may be combined with a mass spectrometer to detect mass fragments of species volatilized during sample heating. Mass loss with heating can reveal copolymer ratio, moisture content, volatile additive content, and inorganic filler content. The decomposition behavior of polymer samples at higher temperatures can also reveal information regarding the extent of chain scission and cross-linking in the polymer.

All weights of samples were recorded at room temperature. The loss of weight result is 0.83 mg/cm² is less than 1.5 mg/cm² (Table 3), so it can be said that this test complies with the standards of (IEC) and shows good stabilization.

Table 3
Weight loss test results

Designation of tests	Unit	Prescribed	Measured	Conformity
Loss of weight After aging for 7 days duration of the test: 1 hour at 150 °C±3	-	≤ 1.5 mg	**0.83 mg**	true

Exposure of insulation material to environmental stressors can lead to changes in polymer chemical properties including loss of molecular weight, cross-linking, release of volatiles (additives and plasticizers), functional group transformation (such as carbonyl formation), and polymer backbone conjugation [20].

3.8 Thermal Shock Test

This test is conducted according to the protocol presented in [20]. In this test, the (IEC) standards recommend the condition of no cracking then the result of this test is consistent (Table 4).

Table 4
Thermal shock test result

Designation of tests	Unit	Prescribed	Measured	Conformity
Resistance to cracking Duration of the test: 1 hour at 150 °C±3	-	No cracking	**No cracking**	true

All of these mechanical properties are related to changes in polymer structure and composition. Other influenced mechanical properties are creep, recovery and relaxation time that are related to ability of a stressed polymer to recover over time. Mechanical property modifiers such as plasticizers, processing aids and other additives can be altered by loss of these additives over time. For example, a small loss of plasticizer can significantly alter the elongation and modulus of the material these conclusions are in good concordance with those of [22].

Any changes to the material composition have a related effect on these other properties. The most common change to the polymer backbone from environmental degradation is chain scission; the cleaving of a one polymer molecule into two pieces.

Polymer chain damage can occur in three different ways: (1) chain scission at the ends of the polymer backbone, (2) chain scission randomly along the chain, and (3) chain scission of side pendants from the main backbone. Chain scission decreases polymer molecular weight and affects various other properties such as mechanical (strength and/or modulus), physical (density, glass transition temperature), and electrical (dielectric) performance. The free radicals responsible for chain scission can also lead to the formation of new bonds in the materials, including cross-linking between polymer chains that further alter material properties our remarks and concluding are validated by those of Crawford [23].

4. Conclusion

In this investigation, the aim was assessing and quality tests of new PVC electrical cables outer sheath. Our investigations based on the IEC standard have shown that the mechanical properties of PVC ST2 have been affected by accelerated thermal aging at 100 ° C and 135 ° C. We found, in fact, a slight drop in the order of 9% of the tensile strength and elongation at break. This decrease is directly related to accelerated thermal aging. By comparing these results with the conditions recommended by the standards of the International Electricity Commission (IEC) it can be said that the test results present good tensile strength and better elongation at break with good stability before and after aging and the loss of mass is very small with no cracking i.e. the mechanical part is complied with the conditions of the standard (IEC). Therefore, PVC ST2 IRIS is very mechanically reliable and can be used as an outer sheath of electric cables. For laying of cables at ambient temperature, PVC ST2 IRIS is good and then without larger mechanical stress, this material keeps good mechanical properties up to the temperature of 150 °C±3.

References

[1] Shwehdi, M. H., M. A. Morsy, and A. Abugurain. "Thermal aging tests on XLPE and PVC cable insulation materials of Saudi Arabia." In *Electrical Insulation and Dielectric Phenomena, 2003. Annual Report. Conference on*, pp. 176-180. IEEE, 2003.

[2] Dissado, Len A., and John C. Fothergill. *Electrical degradation and breakdown in polymers*. Vol. 9. IET, 1992.

[3] Champion, J. V., and S. J. Dodd. "The effect of voltage and material age on the electrical tree growth and breakdown characteristics of epoxy resins." *Journal of Physics D: Applied Physics* 28, no. 2 (1995): 398.

[4] Champion, J. V., S. J. Dodd, Y. Zhao, A. S. Vaughan, M. Brown, A. E. Davies, S. J. Sutton, and S. G. Swingler. "Morphology and the growth of electrical trees in a propylene/ethylene copolymer." *IEEE Transactions on dielectrics and electrical insulation* 8, no. 2 (2001): 284-292.

[5] CHOUAIRI, Asmâa, Abdelkader BENALI, Mohamed EL GHORBA, Nicolas BARBE, and Anass BENOUNA. "Étude de la résistance à la fatigue et analyse de l'endommagement des conductrices aériennes basses tensions issues des réseaux de distribution électriques." *21ème Congrès Français de Mécanique, 26 au 30 août 2013, Bordeaux, France (FR)*(2013).

[6] Zaikov, G. E., K. Z. Gumargalieva, T. V. Pokholok, and Yu V. Moiseev. "PVC Wire Coatings: Part II Characterizations and Performance Predictions." *International Journal of Polymeric Materials* 39, no. 3-4 (1998): 261-288.

[7] Nedjar, Mohammed, Abderrahmane Béroual, and A. Boubakeur. "Influence of thermal aging on the electrical properties of poly (vinyl chloride)." *Journal of applied polymer science* 102, no. 5 (2006): 4728-4733.

[8] PINKEROVA, M., and R. POLANSKY. "ANALYSIS OF THERMAL AND MECHANICAL PROPERTIES OF CABLE INSULATIONS DESIGNED FOR OPERATION UNDER EMERGENCY CONDITIONS."

[9] Standard 60502-2 © CEI 2014

[10] Standard 50363-0 EN 2011

[11] R. N. Farahana, A. G. Suprib and P. L. Tehc, "Effect of PVC-MA Coupling Agent on Tensile, Water Absorption and Morphological Properties of Recycled High Density Polyethylene/Ethylene Vinyl Acetate/Eggshell Powder Composites." *Journal of Advanced Research in Materials Science* 10, no. 1 (2015) : 1-11.

[12] 540 © CEI, "Méthodes d'essais pour les enveloppes isolantes et les gaines des câbles électriques rigides et souples (Mélanges élastomères et thermoplastiques)", Edition 1983.

[13] Standard 608 116 401© IEC

[14] NFT 46.002, Essai de traction, Septembre 1988.

[15] Gillen, K. T., M. Celina, and R. L. Clough. "Density measurements as a condition monitoring approach for following the aging of nuclear power plant cable materials." *Radiation Physics and Chemistry* 56, no. 4 (1999): 429-447.

[16] Standard CEI 60502, « Câbles d'énergie à isolant extrudé et leurs accessoires pour des tensions assignés de 1 KV (Un = 1,2 kV) à 30 kV (Un = 36 kV) », 2005.

[17] Akhil M. V. and Reddy P. S., "Experimental investigation on mechanical properties of coal ash and fly ash reinforced glass fiber polymer matrix composites." *Journal of Advanced Research in Materials Science* 31, no. 1 (2017): 1-9.

[18] Younan, A. F., A. M. Choneim, A. A. A. Tawfik, and K. N. Abd-El-Nour. "Electrical and physical properties of ethylene—propylene—diene monomer (EPDM) rubber loaded with semi-reinforcing furnace black." *Polymer degradation and stability*49, no. 2 (1995): 215-222.

[19] Y. Mecheri, “Influence du mode de vieillissement thermique sur les propriétés du PRC utilisé dans l’isolation des câbles moyenne tension », Thèse de Doctorat, Ecole Nationale Supérieure d’Art et de Métiers, Paris, 2012.

[20] 60811-509© CEI : 2012 Essai de choc thermique (fissuration)

[21] J. Scheirs Compositional and Failure Analysis of Polymers: A Practical Approach. John Wiley & Sons, Ltd. 2000.

[22] Vanderbilt. Vanderbilt Rubber Handbook, 14th Edition. R. T. Vanderbilt Co. Inc., Norwalk, Connecticut, 2010.

[23] Crawford RJ. 1998. Plastics Engineering, 3rd Edition. Elsevier.